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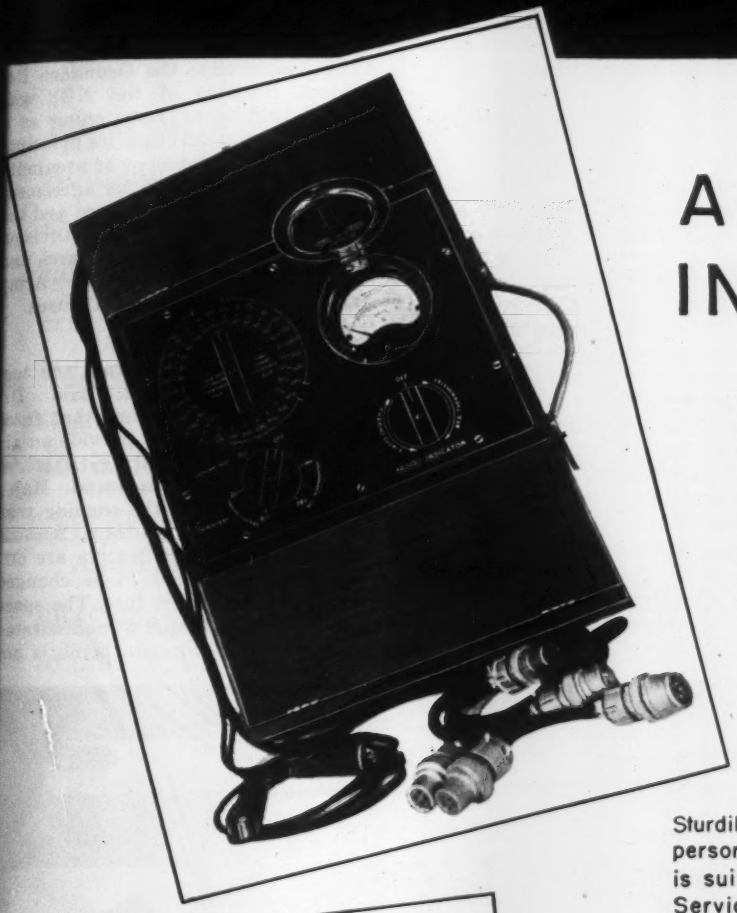

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INSTRUMENTS ON THE MARCH

The Radio Proximity Fuze

WASHINGTON, D. C.—One of the most spectacular stories of highly secret weapons released since the war is that of the radio proximity fuze, officially known as the VT (variable-time) fuze, according to Dr. Harry Diamond, Chief of the Ordnance Development Division of the National Bureau of Standards. This fuze automatically explodes a projectile at just the right time to cause the maximum damage to the target. It was one of the first weapons sought by the National Defense Research Committee, after its formation in August 1940, as a solution to the threat of enemy aviation. Under the joint sponsorship of NDRC and of Army and Navy Ordnance a project was initiated at the Bureau for the development of a fuze for smooth-bore or non-rotating projectiles — such as bombs, rockets and mortars. The development of this fuze ranks as one of the great scientific achievements of the war. Moreover, the developments and techniques embodied in the fuze may be applied to many industrial and commercial applications where ruggedness and size of equipment are important. Subminiature controls and special research equipment represent industrial applications while commercial uses include smaller instruments, tiny hearing aids, pocket radios, etc.

The radio proximity fuze is a tiny radio sending and receiving station. When an object of reasonable size is approached, the fuze receiver picks up the reflected waves, analyzes them and, when the projectile is close enough to the object, an electronic switch is closed to explode the charge.

Basic components of VT fuzes so far developed are: (1) miniature vacuum tubes, rugged enough to withstand 20,000 *G*; (2) a miniature rugged battery or generator; (3) safety devices to prevent premature bursts.

Beginning with a staff of eight in early 1941, the fuze development group at the National Bureau of Standards grew to 400 in 1945, aided by the consultative service of all the regular Bureau Divisions.

Development work started much earlier in other countries. Great Britain was working on the idea in 1937 and sent a commission to this country in mid-1940 which gave American scientists the benefit of their experiences. Germany had started in the early thirties but made the mistake of too great diversification of methods of approach. In contrast to the Germans, our scientists spent a short time of careful preliminary experimentation on the various possible methods. Discarding all but two, they concentrated on the photoelectric and radio types. When the radio device proved superior all activity was devoted to it.

Fuze development was continually handicapped by testing difficulties, said Dr. Diamond. The radio signals must be constant to about one part in 10,000 despite the rough treatment the fuze receives in projectiles. Air turbulence and drag limit bomb velocity and a large amount of energy is dissipated in sound and in vibration. The flight time of a bomb or rocket is never over one minute, which is a short time for experimental work on a remote fast-moving object. Telemetering and statistical methods were successfully applied to the testing.

More than 1000 fuzes for the M-8 airborne rocket were built in the Bureau's model shops during June and July and, by August 1942, the first detailed specifications were completed. Production was started in the latter part of 1942 and continued through most of 1943. About 400,000 each of the radio and photoelectric proximity fuzes were manufactured, said Dr. Diamond.

While the early radio proximity fuze for rockets was developed primarily for use in air-to-air attacks against enemy bomber formations, the design fortunately proved correct also for use from airplanes against troops and gun emplacements, and for use from the ground against such targets. One spectacular application was its use as a barrage weapon from large tanks.

At the same time the Ordnance Development Division of the NBS was organized and began functioning as a separate Division devoting its principal energy to the development of proximity fuzes. Since May 1, 1945, by agreement between the Chief of Ordnance and the Director of the Bureau, this Division has functioned as the sole research and development agency of the Army Ordnance Department on VT fuzes.

The Bomb Fuze

As the war progressed and the tactical situation changed, said Dr. Diamond, it became evident that fuzes for air-to-ground use, to provide an air burst over personnel and light matériel targets, were highly essential. Major share of attention for the ensuing year was devoted to this problem. Because the vehicle and the application are different, the circuit had to be changed from that of the rocket fuze. The space into which the fuze must fit necessitated physical redesign. Since a bomb is not

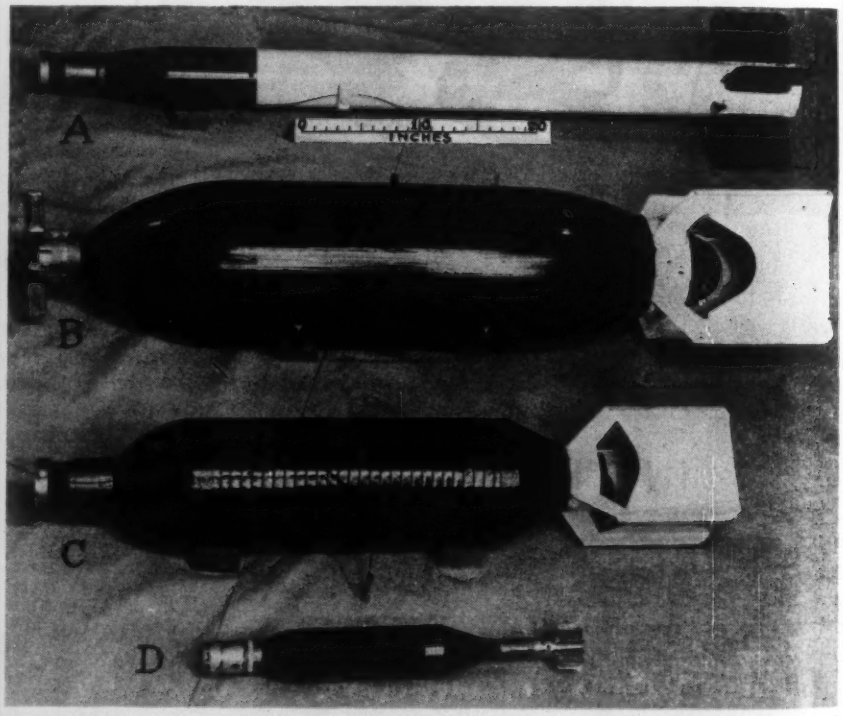

Fig. 1. Four military missiles with characteristic radio proximity fuzes developed by the National Bureau of Standards.

(A) 5" high-velocity aircraft-fired rocket with ring-type rocket fuze.
(B) 500-lb. general-purpose bomb with the bar-type fuze shown in detail in Fig. 2
(C) 260-lb. fragmentation bomb with ring-type fuze.
(D) 80-mm. mortar shell with generator-powered fuze.

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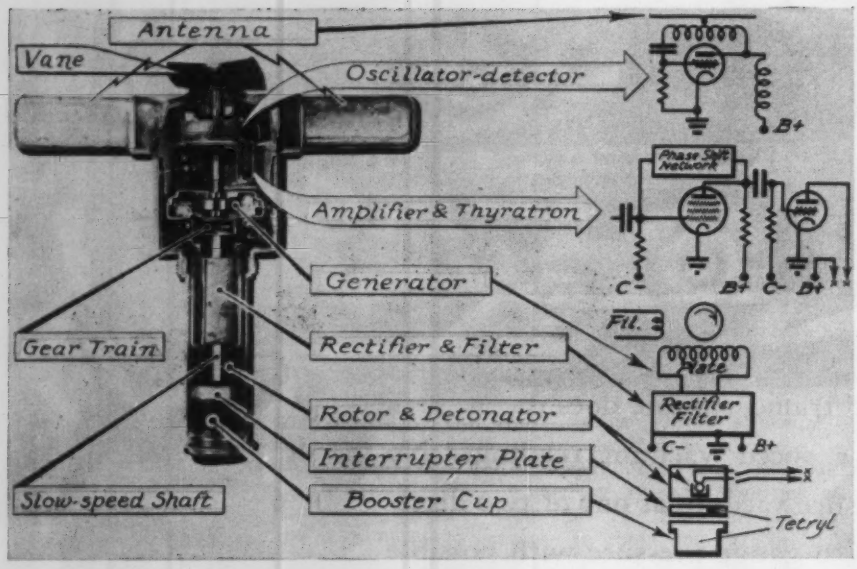

Fig. 2. A cutaway view of the bar-type fuze and circuit diagrams of primary sub-assemblies.

subject to setback at release, as is a rocket fuze, a new arming mechanism was necessary.

Experience with the rocket fuze demonstrated that the usual type of dry battery is not very satisfactory as a power source. It became a "must" to devise a new means for supplying power to the fuze.

In the initial development of VT bomb fuzes, the "longitudinal excitation" type of antenna was utilized, because both the air-to-ground and air-to-air aspects had to be kept in mind and because electric circuits for this type of fuze were better known. Soon after, work on the "transverse excitation" type of antenna was also initiated. This offered advantages in air-to-ground bombing: (1) better performance from high altitude, (2) less dependence on bomb dimensions, (3) greater sensitivity—i.e., greater burst heights.

An air travel arming system was selected, in which arming occurs only after a small vane at the front of the fuze has turned through a certain number of turns. Use of this wind-driven propeller led to a solution to the power supply problem: the rotating system may be utilized to drive a generator. The requirement for a generator of small size, high power output, rugged design, stable operation, and simple construction led to the development of a permanent-magnet alternator. An electrical regulator was developed which maintained constant generator power over a rotational speed range of three to one.

The next problem, said Dr. Diamond, was to minimize the vibration resulting from the rotation of the propeller and the generator rotor. By using a turbine, mounted inside the fuze close to the generator rotor and driven through a central air intake duct, it is possible to make the rotating system more compact. By locating the generator within the fuze well of the bomb, the entire rotating system is mounted close to the point of support, reducing over-all length and vibration amplitudes. Development of the generator was a milestone, but not an unmixed blessing. The required speeds (in excess of 50,000 rpm.) dictated that effort be devoted to bearing design, to balancing the rotating mechanism, and to improving the rotor structure so that it would not fly apart. All of these problems were solved.

Production of the generator-powered bomb fuze began during the latter part of 1943. The vibration problem remained difficult. It was found necessary to manufacture certain mechanical components to extremely close tolerances and to develop miniature radio tubes which were insensitive to vibration to a degree previously unknown. A machine for dynamically balancing the small Alnico rotor under production-line conditions had to be devised.

Among minor modifications in the course of production was a device to provide delay in arming (in addition to that built into the fuze) which could be adjusted in the field to permit the fuzes to be dropped safely through deep formations of bombers. It consisted of a small auxiliary vane and gear train externally clipped to the fuze, which released the fuze vane after a pre-selected amount of air travel.

THE GENERATOR-POWERED ROCKET FUZE

After the bomb fuze development had passed into the manufacturing stage, the Navy proposed that this type be

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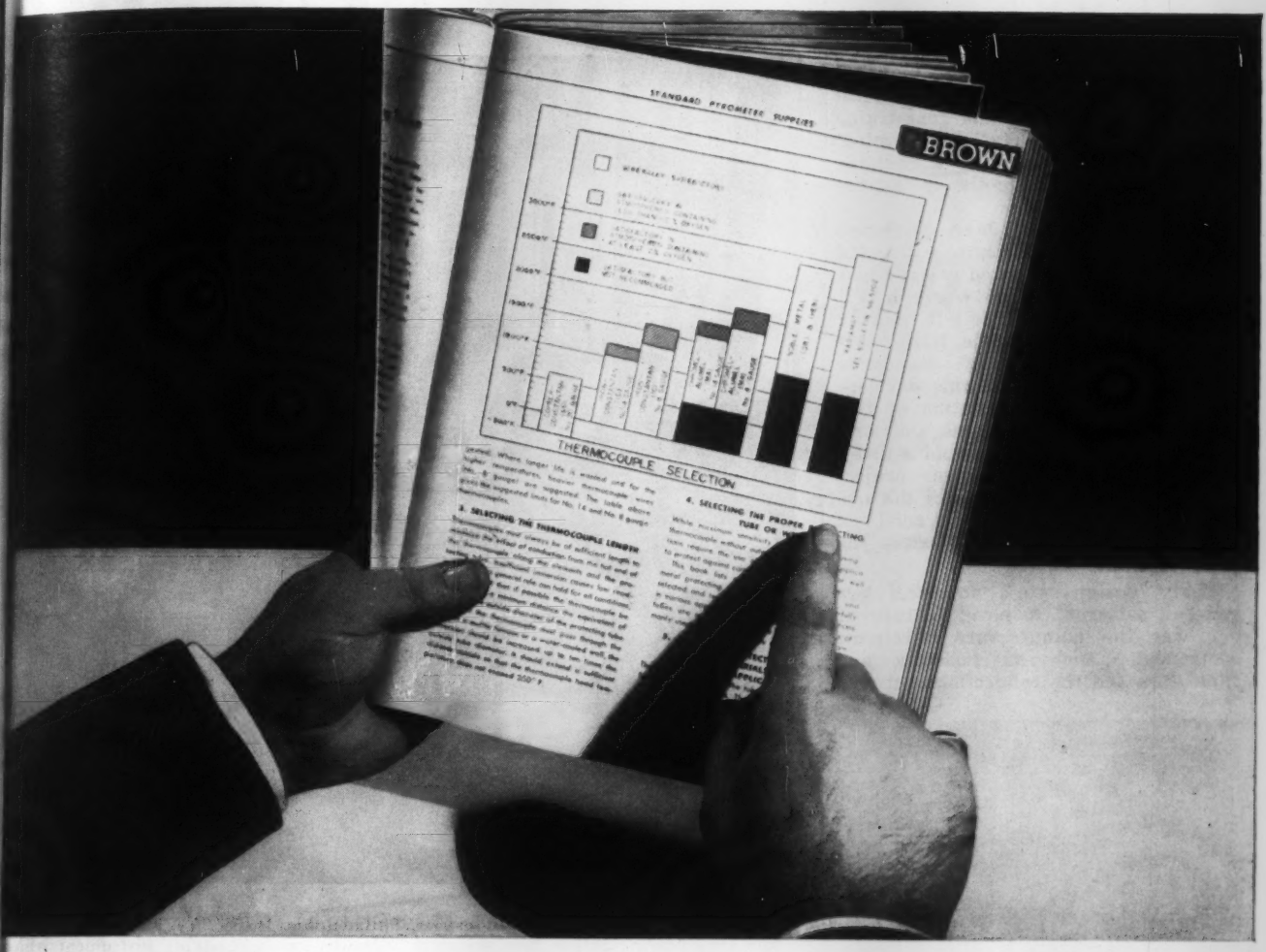

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adopted for use on the new Navy 5" aircraft rockets. Development of a new rocket fuze meeting all service requirements was virtually complete in June 1945. It featured an enclosed turbine drive for the generator and gear train, self-destruction and variable arming time as field options, and a change-over switch for air-to-air or air-to-ground operation.

After VT fuzes had been developed and produced for all common projects except trench mortars and designs had progressed to the point where a VT fuze small enough for the 8-lb. mortar projectile appeared possible, NDRC and the National Bureau of Standards were asked to undertake this development. It required the solution of two major problems: ruggedness and size. A mortar fuze must withstand a firing shock of 10,000 *G* and mortar projectiles are so small that fuzes of the size of those used on bombs would spoil the flight of the projectile and make the round useless.

Early design work followed two general patterns. A novel feature of one was the manufacture of circuit components, such as resistors and capacitors and the connections between

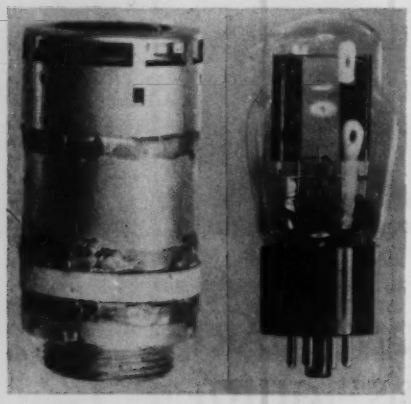


Fig. 3. The generator-powered proximity fuze for mortars measures only 4¾" in length with an over-all diameter of 2". Note conventional radio tube for size comparison.

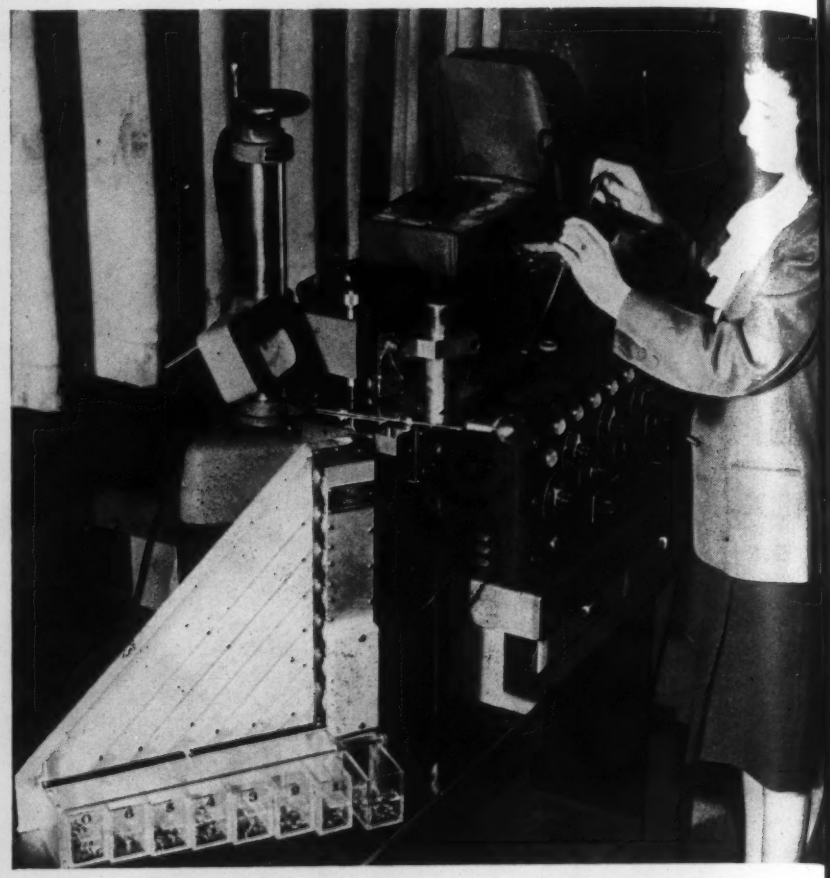
them, by a new process. [EDITOR'S NOTE. — See "Printing Electric Circuits," *Instruments*, April 1947, pages 366-367.] The second design used a small loop antenna instead of the projectile body antenna. The circuit design and power supply followed closely the designs of previous fuzes. The operating characteristics of the two types of fuzes differed in the same manner as the characteristics of the two types of bomb fuzes previously described.

Again the urgency of the need for the fuzes dictated production prior to completion of development. Development and preparations for production proceeded simultaneously and in June, 1945, production got under way.

PRODUCTION

The radio fuze presented an enormous challenge to production engineers. It is generally called an electronic de-

PICTORIALS



SORTS SIX SIZES—At SKF Industries, Philadelphia, Inspector Violet Manion feeds tiny steel bearing rollers into automatic measuring-and-classifying instrument which gages them to tolerances within 20 microinches, sorts them into six varying sizes and rejects misfits, all at the rate of 60 per minute.

FIRE ONE: The conning tower, nerve center of a U.S. submarine, at the moment of firing a torpedo at an enemy vessel. The periscope was made by Kollmorgen Optical Corp. *(Photo courtesy Universal Newsreel, by permission U.S. Navy Department)*

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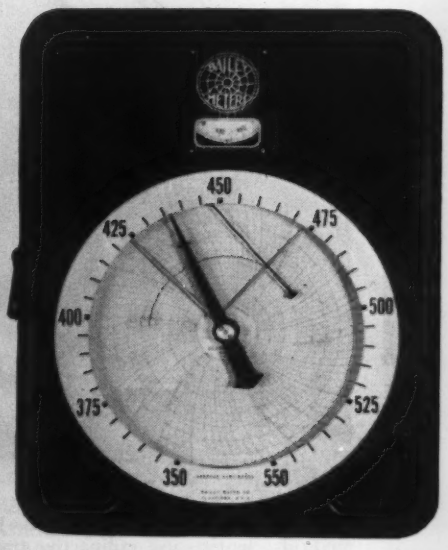

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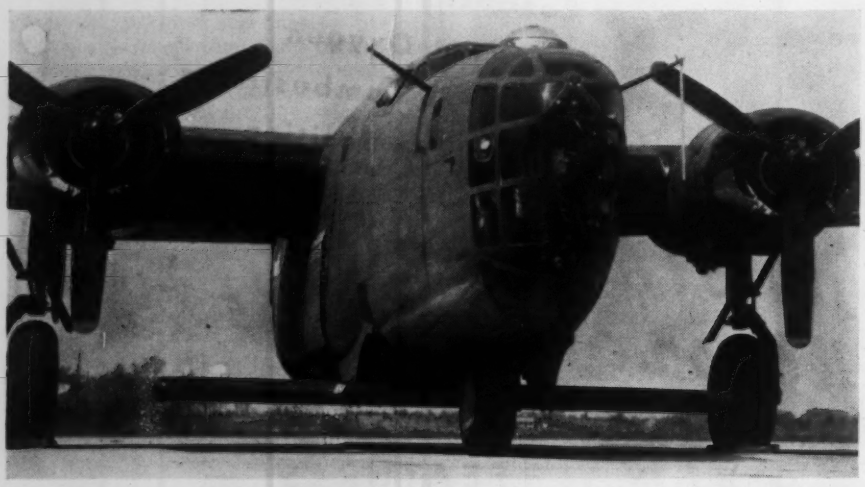
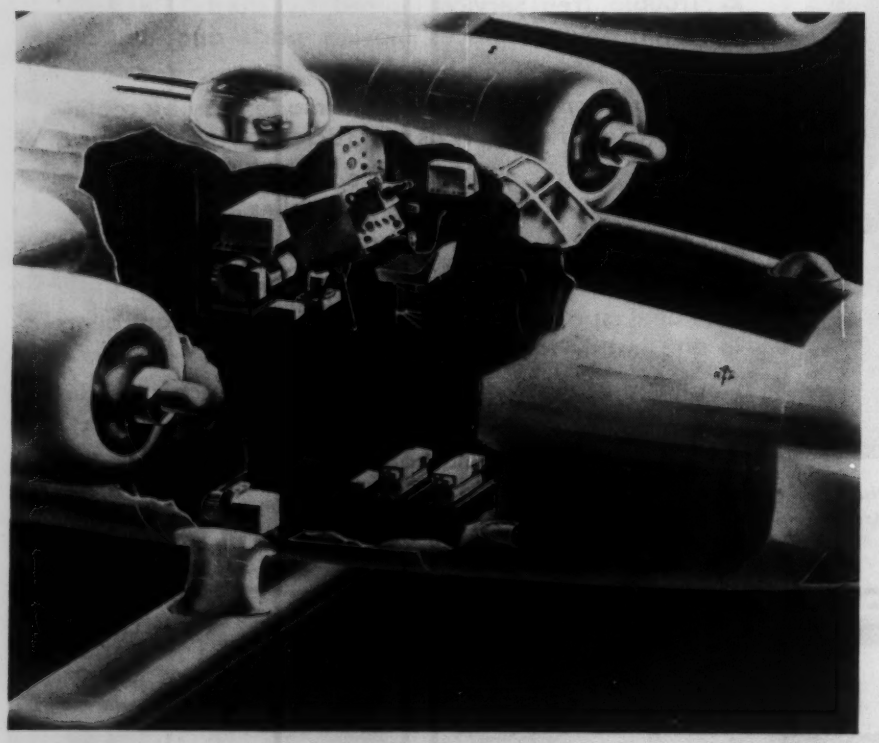
vice, and yet it is more complex mechanically than electrically. Designs required a nice balance between the perfection and the producibility of each part. The radio fuze is comparable to a highly-sensitive radio instrument electrically and to a fine time fuze mechanically. Few manufacturers were completely qualified in both fields. Add to this fact that in each instance production was required before the development work was complete, and it is apparent that the production task was as large and difficult as the development of the fuze. To handle its phase of this task, the Bureau established a Production Engineering Section in March, 1943.

A parallel major development by the Applied Physics Laboratory, Johns Hopkins University, conducted under Navy and OSRD auspices, had made available VT fuzes for rotating projectiles, such as artillery and anti-aircraft shells. To prevent the enemy from capturing and duplicating the VT fuze, its use was limited to naval activity on the high seas until the last stages of the war when it was too late for the enemy to use the information.

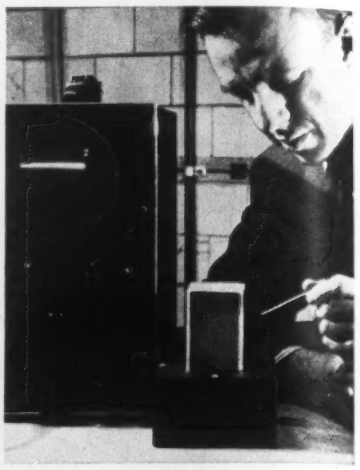
VT fuzes then spread rapidly to all zones of combat for use by strategic bombers, assault fighters, carrier-based aircraft, and naval and artillery gunners. The quantities of proximity fuzes used in combat continually increased and with it, necessarily, production. By the end of the war, one fourth of the radio industry was engaged in the production of VT fuzes.

Since the end of the war, industry has manifested interest in the application to peacetime uses of the ideas and processes developed during the fuze program. Many industrial and government organizations are conferring with the NBS, concluded Dr. Diamond.

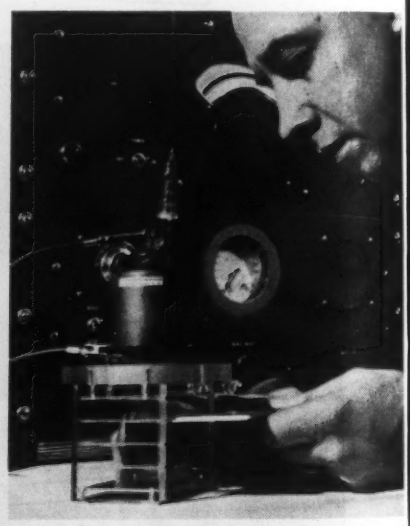




"EAGLE."—Disclosed in these AAF photos are details of the much-discussed "Eagle" radar. Above, the 16-foot airfoil housing the antennas. Below, section of pilot's compartment in a B-24 showing details of the instrumentation.



FASTEST!—100,000 per second is the radiation counting rate of this new detector shown in action here with Dr. Fitz-Hugh B. Marshall of the Westinghouse Research Laboratories. Fifty times more effective than the standard Geiger counter, it is still in the experimental stage.



ATOMS TRACED IN METAL.—Just as medical scientists use radioactive tracers to study living organisms, scientists at the Westinghouse Research Labs follow the progress of radioactive atoms through the internal structure of metals. Here James K. Stanley, Westinghouse research engineer, counts the particles emitted from a small sample of metal which has been injected with a dose of radioactive carbon. Migration of the carbon is followed through the metal by means of a Geiger counter and by periodic photographs. Such migration of carbon is believed to be one reason why steel ages and becomes brittle.

Instruments THE MAGAZINE OF Measurement and Control

M. F. BEHAR, Editor

Research ⇌ Instruments

DETAILED reports of the Instrument Society of America's Second Annual Conference and Exhibit, held in Chicago September 8-12, will appear in our October issue, mostly in the *ISA Journal* section. This brief account can only hit the high spots. Highest in our mind is the new mutuality of Research and Instrumentation.

Although the ISA is not an engineering or scientific society, an astonishingly large number of eminent engineers and scientists, from laboratories devoted to "pure" as well as to "applied" research, came to view the exhibits, to attend some technical sessions and (so it seemed at times) to seek out and quiz your humble servant. Our most vivid impression is that officials of institutional as well as company labs are suddenly discovering that they have been committing a crime. Since they are law-abidding, we must explain: In numerous conversations we were told that the commercial availability of "special-purpose" instruments was a revelation, that less time would henceforth be wasted on "new" designs and that *The 1948 Instruments Index* would henceforth be USED! Then we would smilingly quote Dr. McDonald's phrase so often printed on this page: "that crime against research—duplication of effort" and the interviewer would laugh: "Guilty in the past but fully reformed now!" Then we would both agree with the assertion made last year by Paul Exline of Gulf Research: "Almost the entire product of research is data obtained from measurements made with instruments." Often the conversation would turn philosophical: instruments and research are both causes and effects . . . a radically new "apparatus" which is the fruit of research may consist of standard instruments and components . . . and so on.

By the way, Paul Exline was elected ISA President and his administration will no doubt signalize the mutuality of instruments and research, will no doubt enhance the prestige of laboratory Instrument Departments (whose heads now suffer under such titles as "mechanician," etc.).

Second-highest spot: a not-for-publication avowal by an electronics expert that he is yanking out tubes and plugging in magnetic components in some types of applications.

Automaticity received a triple boost: (1) Professor Donald Campbell of M.I.T. disclosed his new method of analyzing and synthesizing automatic-control systems — a twenty-minute method which by-passes the hours of Nyquist analysis, just as Nyquist by-passed the days (or weeks!) of solving high-order differential equations. (2) G. F. ("Gerry") Akins again put on his automatic-control demonstration with a complete "process" and a giant-size "recorder-controller" on the platform. (3) C. E. ("Doc") Mason again gave his lecture on "The ABC of Automatic Control," and again his audience included admiring "highbrows."

The high cost of living, though not specifically dealt with, was shown (by inference) to be a consequence of America's tragic failure to CONTINUE increasing productivity, reducing the labor content of everything that is sold and otherwise abolishing repetitive drudgery through Instrumentation.

The ISA membership (including Canada and South America) is just over two thousand. More than seven thousand persons registered. Whatever conclusion one draws, it must include the word SUCCESS and some expression such as "powerful magnet attracting visitors from all industries and occupational groups."

—MFB

What About Our Instrument Industry?

To the Editor of *Instruments:*

From an inconsequential position in the realm of instrumentation, it appears that the high-tide level which our American Instrument Industry held during the war is slowly ebbing. After having filled our war-time needs, having accomplished its purpose, it is no longer of primary importance. Like a life-raft after the rescue, it is discarded.

Tempus fugit, et homo obliviscetur.

Authoritative persons in our instrument industry reveal disturbing facts. Particularly conspicuous is the disclosed fact that, at present, the all-important jewel-bearing industry is non-existent in our country. Ever since the invention of the hole jewel by Fatio de Duillier in 1700, the incorporation of jewels in the manufacture of precision instruments has proved to be necessary. Its importance is great enough to warrant the existence of an American jewel-bearing industry.

Another disturbing factor worthy of mention is the apparent discontinuation of commercial stop-watch manufacture. That an industrial power—such as our country is today—should have to rely upon foreign manufacture, is indeed perplexing.

From a conglomeration of theories advanced as to the cause of this unseemly state of affairs, the inadequacy of present tariff rates is most prominently mentioned. It undoubtedly is of cardinal importance that a tariff wall be erected to protect our American instrument industry and its workers. It also is equally essential that eternal vigilance be exerted through the years in order to insure constant protection. However, a high tariff rate is seemingly merely a palliative.

When we consider that the human element is a predominant factor in the creation of an instrument industry, it seems quite correct to believe that it is the obligation of our American instrument industry to assume the responsibility of developing and educating the qualified personnel necessary to fulfill our country's increasing demand for instruments of greater refinements.

To think that the development of the natural powers is a remedy in itself might be an immature thought; to think that, in our time, important advancements in instrumentation can be realized only with the assistance of physics' most modern resources seems obviously correct.

The nature of today's instrumentation problems cannot be solved without the assistance of qualitative education that will contribute to the improvement of the products of the instrument industry and also to its scientific development.

GASTON WILEY

Jersey City, N. J.

CORRECTION NOTICE

In *The 1948 Instruments Index*, page 56, under "Motors, Fractional-hp.," change "Cyclone" to "Cyclohm."

On page 112, in the alphabetical list of manufacturers, change "Cyclone Motor Corp." to "Cyclohm Motor Corp."

Servomechanisms, Semeiology, Stability and Satisfaction

By M. F. BEHAR

YOU have—no doubt—invented guided missiles and target-seeking missiles . . . at least in your daydreams. So imagine, now, that you are demonstrating your new jet'copter at the Muroc, Calif., Air Force speed-test field. You are overlooking the famous measured straight-line course (a black tar guide strip twelve feet wide and three kilometers long) in a lofty control tower just erected in your honor. The course has recently been marked off into 64 equal divisions, with an extra-long cross-mark at 32. Dr. Bob King and his men are at their high-speed moviecams and millisecond timers.

Your jet'copter is hovering at 300-foot altitude over the south end of the course. It is hovering on its ordinary gasoline-powered rotor: the two jets are off. Yes, there are two jet units: one—termed "A"—for forward flight and one—termed "B"—for "braking." You can turn on either of them by radio.

You can do even better—and this is your invention—you can command the jet'copter to proceed from "here" to "there" by ONE signal, so that relatively unskilled personnel sitting in comfortable ground stations can maneuver pilotless jet'copters laden with mail, freight or bombs.

So important is this feature that famous observers crowd your control room: Bill Brombacher from the NBS, Hugh Dryden from the NACA, Charlie Stanton and Ed Patton from the CAA, Gen. Curtiss LeMay from the Air Force, Adm. Luis deFlorez from the Navy, Colonel Leslie Simon from Army Ordnance, Major Gardner from the IAS, Ray Kelly and others from the air lines, Preston Bassett and others from the manufacturers, and—most attentive—Professors Hazen, Draper, Brown, Campbell and others from MIT. Undistinguished observers such as tech mag eds prudently keep out of your way.

To the observers you explain the first test, which is about to start: "This portion of the Master Control Desk, resembling a 64-centimeter rule, is divided like the course from 0 to 64. This slider is at 0 and, as you see, the jet'copter is hovering exactly over 0, because that is where my special combination FM and pulse-code VHF radio beam is positioned. I shall suddenly move the slider to 32 and then step back, away from the controls, to make it obvious that the flight from 0 to 32 is entirely automatic. One moment for a last check-up of all circuits . . . All right, now watch!"

You suddenly shift the slider to 32 and step back.

With a deafening roar the A jet spurts. The J-C seems to start as fast as a bazooka rocket. . . . It's traveling horizontally, beautifully maintaining its 300-ft. altitude. . . . It speeds north without deviating from the straight-line course. . . . Faster and still faster. . . . Now it's nearing the half-way mark and in a split-second it's over it!

But it doesn't stop! What is seen to happen is that as the J-C crosses the half-way mark the A jet goes off and the B jet goes on. There is not the true braking of a train on rails or of an automobile on a road surface: the retarding force is that of the B jet. Both

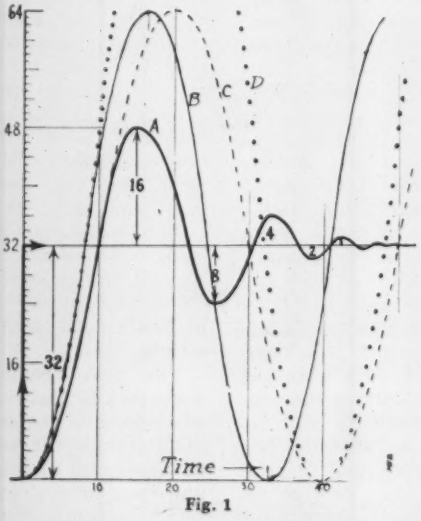


Fig. 1

jets have equal power ratings; therefore the J-C's own decelerating force is exactly equal to its accelerating force. Were it not for the air drag, the J-C would come to rest at the *end* of the course: at 64. Because of drag it only goes as far as the three-quarter mark—at 48.

Since the J-C is automatic and is "set" to come to rest in the narrow VHF radio beam you have positioned at 32, its B jet does NOT go off at 48 and the J-C is seen to pause only momentarily and start back like a bazooka rocket.

Its momentum carries it south past 32. As it crosses 32 its B jet goes off and its A jet (which now serves as the "brake") goes on. The J-C travels south—not as far as 16 but only to 24. There it reverses, crosses 32 and goes as far as 36 where it reverses. Its next trip carries it to 30; its next to 33; its next to 31.5; then 32.25; then 31.875; then 32.0625 . . . but the next time the B jet does *not* go on as the A jet goes off and the J-C hovers near 32—so close to 32 that part of it is right over the mark. Success!!

Almost at once, the Instrumentation Group hand you the record instantaneously autographed by their specially-invented "Four-pen Performance Recorder-computer-predictor." (See Fig. 1.) The heavy-line curve A shows the course of your J-C as acted upon by its two jets AND BY AIR DRAG. (To you it is important as proving the success of your J-C.) An easily-remembered fact is that your jet'copter crossed the 32 mark the first time exactly ten seconds after the start.

The thin solid line B shows the course your J-C would have taken if it were so ideally streamlined as to fly WITHOUT AIR DRAG—that is to say, acted upon ONLY by its two jets, one at a time and each delivering the same thrust as in the test.

The dashed line C is likewise an "iffy" or "no air-drag" record autographed by the computing mechanism of the marvelous recorder. It shows the record that would have been produced with no air drag and with the thrust of each jet reduced so that the J-C would cross the 32 mark the first time in exactly ten seconds. (One complete cycle would then equal forty seconds.)

Dotted line D, simultaneously traced by the computing instrument, shows the record that would have been made without air drag and with your slider set at 48 instead of 32. Is it a mere coincidence that the period is exactly forty seconds or is a natural physical law involved somehow? But you don't care: you have eyes only for curve A, showing that your J-C came to rest at "exactly" 32—closer than the severest imaginable specifications for mail, freight or bombing!

You start explaining to the visitors that your VHF beam has side bands of a *spatial* type and that its sharp peak is not infinitesimally narrow. But most of them have their backs to you: without even saying good-bye they get into the elevator. Virile though you are, you burst into sobs, rush to the outer platform, climb over the guard-rail . . . but you halt as you hear a behest to behave:

"Don't rob mankind of a promising inventor!"

The manifestly-fearful bystander goes on: "All you need is to equate cap pee to cap kay theta plus cap ell times dee theta over dee tee; then to equate these two expressions to cap jay times dee two theta sub oh over dee tee square plus cap eff dee theta sub oh over dee tee; then add cap en times integral of theta dee tee on the left side. Then . . ."

"Cut out that Greek!" you say.

"Theta is college English" insists the math-flaunting ballistician, "It's simply the difference between the position of your J-C, which is theta sub oh meaning output, and that of your beam—which, by the way, is theta sub eye meaning input."

"What has that to do with the cruel way the experts ignored the success of my J-C?" you ask.

"Everything! They left because your J-C is NOT a success. I was telling you that you can't cure hunting without adding—in your J-C or in your control desk, which is part of the system—some gadgets to improve the system by error-rate and viscous-output damping and

*Any similarity between this sprightly article and a presentation before a scientific society is unintentional. (Exception: Figs. 7-12 incl. which are from technical papers by the author.)

integral control — some gadgets well-known to control-system designers.

"Well, I'm not a designer! I happened to dream up that jet'copter but my job is to USE control instruments. What I want to know is the practical dope which most of you control connoisseurs conceal behind a cobalt curtain of calculus."

Here is "practical dope"—mostly pictures—some specific significant subjects selected as stepping-stones to sesquipedalian servomechanism symposia.

FIRST of all, let's make sure we understand each other. Let it be understood that a servomechanism is a MECHANISM. An automatic-control system without mechanical components is NOT a servomechanism. Many electrical types of automatic-control systems have no moving parts: not one of these is a servomechanism.

Especially fallacious is the idea that all automatic-control systems WITH moving parts are servomechanisms. Some are; some are not. An automatic temperature control system, for example, is not an SM. Indeed, not a single temperature controller in all the world is an SM (though many highly-developed automatic temperature systems incorporate SMs.)

Likewise, automatic regulators without moving parts are not SMs; and as for those with moving parts, some are SMs and some are not. More about this later. Just now, let's remember that a servomechanism is a mechanism.

Now for the SERVO prefix. It clearly means what the letters clearly spell: to serve. A servomechanism is a servant—usually a strong servant capable of quickly moving heavy loads at a signal of command.

A slave?

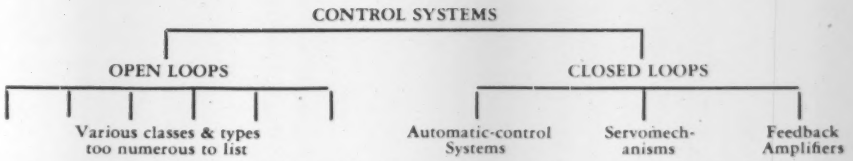
Yes, a slave. But forget the human connotations of "servant" and "slave," for modern SMs are the marvelous brain-children of scientific and engineering geniuses—not only geniuses in practical mechanics and hydraulics but geniuses in theoretical electricity and in mathematics.

Slave and master must not be confused. Socrates was a slave but who remembers his master's name?

The master of a servomechanism may be a human being and, until recently, always was a human being, for, until recently, SMs were used only for positioning the turrets of battleships and for other such heavy "follow-up" functions. Even today it would not be incorrect to say that all SMs are "follow-ups"—but it would be an unjust remark because modern SMs are not mere follow-ups but HIGH-PERFORMANCE follow-ups. An important difference is that an SM knows its own error at all times.

An essential of all SMs is POWER. (Of course, the SM does not generate power but applies it, like a servomotor but more "intelligently.")

A second essential of every SM is that it tries at all times to reduce its own error to a minimum: to ZERO if it is designed without any dead zone or differential gap; to a harmlessly small value if, for example, it is designed with an adjustable electrical-contact device—or with an equivalent inductive, capacitive, electronic, pneumatic, hydraulic, photoelectric or mechanical device.



(Yes, the rational classification corresponds exactly to the Standard Classification of Prime Relays of Automatic-control Systems; see *Instruments* Aug. 1946, pages 446-447.) With an electronic device such as a thyratron, which has an INHERENT dead zone, absolute zeroing is as unattainable as the absolute zero of thermodynamics, but this is a rather academic point and in practice any class of SM—even a mechanical SM with big ratchet teeth—can zero itself closely enough for your satisfaction if you treat it right.

When the master of a servomechanism is not a human being, it is an instrument—usually an instrument which relieves a human being of the drudgery of watching a dial with his eyes and operating a valve or rheostat with his muscles. The combination, then, is an automatic-control system. But, again, two points must be remembered: First, that some automatic-control systems do not have SMs as essential components; second, that in many relay-type automatic controllers the device which utilizes auxiliary power at the command of the primary element is not a servomechanism but a power device or servomotor.

If you have read every word of the foregoing twelve paragraphs you deserve a reward—and it is hoped that the reward will be the satisfaction of knowing that you understand these distinctions better than do some writers on automatic-control theory who mix up their nomenclatures in a gosh-awful way. . . . Tell you what, brother: let's agree that A SERVOMECHANISM IS A MECHANISM THAT MOVES A HEAVY LOAD AT YOUR COMMAND, using auxiliary power such as electricity or air or oil; and—what's important—always trying to obey your signals without error and WITHOUT INSTABILITY.

Okay?

Thanks! Now to discuss stability. We'll try to justify the remark that the experts left in disgust because the jet'copter (a spectacular but "typical" SM) was NOT a success.

To be sure, it was not a complete failure. It obeyed your command to displace a load from 0 to 32, And, as you study its recorded wiggles, you know from experience with some industrial on-and-off systems that it could do worse and still not be a complete failure.

But—just between us, brother, with no experts eavesdropping—it must be admitted that without air drag the J-C would be a ridiculous failure: it would oscillate between 0 and 64 until the fuel gave out.

"Air drag" is a loose term but so useful that we shall keep on using it, for it conveys a vivid idea of the usefulness of one kind of friction. The technical term is *viscous output damping*. This kind of damping slows down the load being moved, but is not necessarily a source of error. The action of a piston-type door check is a good analogy.

And now to disclose a little secret about the chart of the marvelous "Four-pen Performance Recorder-computer-predictor." The whole thing as shown in Fig. 1 could be plotted from only two data:

(1) Starting from a standstill, the J-C travels 32 divisions in 10 seconds when accelerated by a jet and simultaneously impeded by air drag; then

(2) under the forces of jet-thrust PLUS air drag it slows down and travels 16 more divisions.

Yes, the remainder of curve A—and curves B, C and D in Fig. 1—can all be plotted. By a trained mathematician? No: by anyone who has taken the most rudimentary junior-high-school physics course! What's the first thing taught in physics?

Galileo's and Newton's Laws of Motion.

Right! And only easy ones need be applied! And without calculus; only as we learned them when we were schoolboys: in their simple algebraic forms ($f = ma$ and $s = \frac{1}{2}at^2$). And we gain a most useful insight into Automatic Control Science!

While working out the example, let's both bear in mind that it is an example in elementary dynamics—not in temperature control or other actual industrial process control. What you have under your command is not a furnace, still or reactor but A MECHANICAL SERVANT THAT OBEYS YOUR COMMANDS TO MOVE A LOAD.

The speed (strictly, the acceleration) with which your mechanical servant can obey your commands to displace a load depends on the force it can exert. Same rule for stopping: The prob'ems of comfortably decelerating railroad trains in minimal time fill a whole book by Dr. Sillcox—a fascinating book of 274 pages! Newton's Second Law of Motion holds true whether a is positive or negative. It takes as much TIME when $|-a|=|+a|$ and $|-f|=|+f|$ and m remains constant.

You knew this all the time!

But don't let this convenient equality or symmetry of servomechanisms throw you for a loss in industrial automatic-control fields, for the rates of energy consumption may be enormously different. Examples:

(1) Humidity control: Up to the desired value in little time by spraying; but, gosh! what a lot of kilowatt-hours the machinery in the basement eats up to bring the building's humidity *down* to the required value in summer!

(2) Pressure control: Down in almost no time; but the circuit breaker trips if you try to build-up too fast.

(3) Vacuum control: Just the reverse, in that vacuum can be "broken" in almost no time, whereas it takes hours and kilowatt-hours to build up a high vacuum in a large vessel.

(4) Temperature: In a refrigerator application the power required to correct an "up" disturbance is the problem; in a furnace it's the opposite—unless you are one of the few whose requisitions for over-size burners, valves, etc., have been approved. Later on we shall see that the "master"—the primary measuring element—responds in non-Newtonian ways.

(5) Position: The inequality is obvious in such applications as the control of hoists, elevators, etc.

In working out this aircraft SM stability we may make a simplifying assumption: that the effect of air drag is a deceleration (negative acceleration) obeying the familiar law $s = \frac{1}{2} at^2$ [or $a = (2/1)\ (s/t^2)$.] Thus, the J-C moves TOWARD 32 under jet acceleration MINUS air-drag acceleration $(a_J - a_D)$; but when it moves AWAY from 32 it is retarded by the SUM of jet and drag $(a_J + a_D)$.

Another simplification is to disregard the actual values of m and f so as to use only accelerations, distances, velocities and times. This is permissible even in the classroom.

Still another simplification: space units will be expressed in the divisions of the test course instead of feet, miles, centimeters, etc.

From rest at 0, the J-C travels 32 divisions in 10 seconds under the NET acceleration $(a_J - a_D)$. From Galileo and Newton we get

$$(a_J - a_D) = \frac{2}{1} \times \frac{s}{t^2} = \frac{2 \times 32}{10^2}$$

which gives us 0.64 divisions per second per second as the net acceleration toward 32. In all the subsequent wiggles of the J-C, its acceleration when traveling toward 32 is always 0.64 div./sec.^{2}.

In watching the test, we saw the J-C travel to 48 before reversing but we do not know, yet, how long it took to travel these 16 divisions. We remember that the instantaneous speed of a constantly-accelerated body (such as a body falling in vacuum) is twice its average speed up to that instant. The J-C's average speed from 0 to 32 was 32/10 or 3.2 div./sec. and its instantaneous speed when it crossed 32 was $2 \times (32/10)$ or 6.4 div./sec. Therefore, since its deceleration from 32 to 48 was constant, its average speed from 32 to 48 must have been half its initial speed of 6.4 div./sec., or 3.2 div./sec., exactly the same as average speed from 0 to 32; and we can either extend the average-speed straight line from 32 to 48 as in Fig. 2, or we can do mental arithmetic: 3.2 goes into 16 five times. Either way, we find that the time is exactly 5 seconds.

Again from the laws of motion we have

$$(a_J + a_D) = \frac{2}{1} \times \frac{s}{t^2} = \frac{2 \times 16}{5^2}$$

from which we find that $(a_J + a_D) = 1.28$. This is the value for all the subsequent overshoots away from 32.

We have seen that $(a_J - a_D) = 0.64$; therefore we get $a_J = 0.96$ div./sec.^{2} and $a_D = 0.32$ div./sec.^{2}, although we don't need to know these two values for the first part of our graphical solution.

The travel from 48 to 32 is under the net acceleration, jet MINUS drag $(a_J - a_D)$ exactly as from the standing start (at 0) to 16. But how long did THAT take? We don't know yet because we have hardly begun to draw Fig. 2.

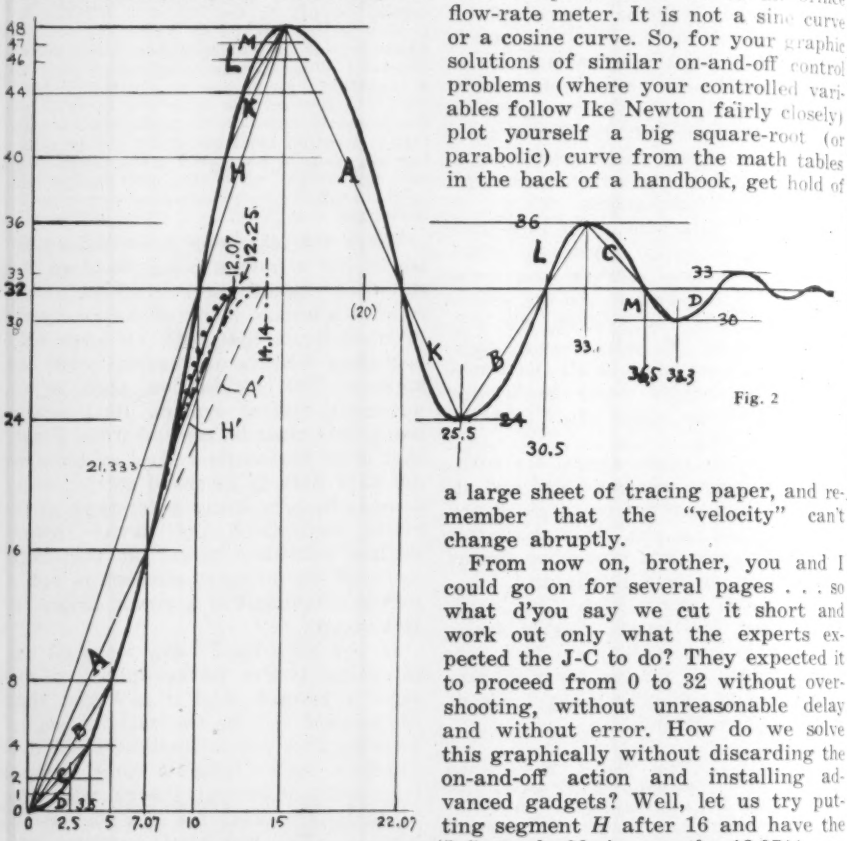


Fig. 2

So we first fill in the two most easily found points for the curve from 0 to 32, by mentally extracting two well-remembered square roots. At 5 seconds, which is half of 10, s is one-quarter of the final distance s_{10}, or 8. At 2.5 sec., which is one-quarter of t_{32}, s is one-sixteenth of 32, or 2. Next, to get t for $s = 16$ ($\frac{1}{2}$ of 32), we look up the square-root of $(\frac{1}{2} \times 10^2)$ or fifty. It is 7.0711.

Therefore, the time from 48 to 32 under net acceleration is also 7.07 seconds. Total time at this point, $10 + 5 + 7.07$, or 22.07 seconds. Instantaneous velocity at this point, 4.52 div./sec.; average velocity from 48 to 16, 2.26 div./sec.

The J-C crosses 32 and now is subjected once more to the sum of a_J and a_D, as it was from 32 to 48 but, specifically, as it was from 40 to 48. Graphically, just as we took segment A and used it from 48 to 32, so now we take segment K and use it from 32 to 24.

From 24 to 32 is the same as from 0 to 8 and we use segment B. Next, we extend the average-velocity straight line from 32 to 36, using segment L. Then segment C to 32 and segment M away from 32; and so on. Always smaller overshoots and shorter periods. The combination of decreasing amplitude and increasing frequency like a steel ball bouncing on a steel plate.

Note also that each curve segment is a square curve or parabolic curve or square-root curve (depending on the choice of aspect) like that of a Pitot-tube airspeed meter or of an orifice flow-rate meter. It is not a sine curve or a cosine curve. So, for your graphic solutions of similar on-and-off control problems (where your controlled variables follow Ike Newton fairly closely) plot yourself a big square-root (or parabolic) curve from the math tables in the back of a handbook, get hold of a large sheet of tracing paper, and remember that the "velocity" can't change abruptly.

From now on, brother, you and I could go on for several pages . . . so what d'you say we cut it short and work out only what the experts expected the J-C to do? They expected it to proceed from 0 to 32 without overshooting, without unreasonable delay and without error. How do we solve this graphically without discarding the on-and-off action and installing advanced gadgets? Well, let us try putting segment H after 16 and have the J-C reach 32 in exactly 12.0711 seconds. (See H' in Fig. 2. The heavy-dot line shows the desired course.) That seems all right at first glance, but it will not work with the J-C type of servomechanism we're studying, because at 16 the J-C has not picked up enough speed to travel another 16 divisions under the additive retardations of jet thrust and air drag. In other words, if the A jet is turned off and the B jet turned on at 16, the J-C will not reach 32 but will only reach $16 + (16/2)$ or 24. The graphic "proof," by the way, is that the average and instantaneous speed lines would be broken.

Next, we try putting segment A at 16 (See A' in Fig. 2. The dot-and-dash line is the desired course.) Seems correct at first glance because the average-speed line is extended without break, but again incorrect for the same reason as before.

Have you guessed the answer? Right! Since we have (by reason of air drag) 50% overshoot after actuation of the snap switches, let's take two-thirds of

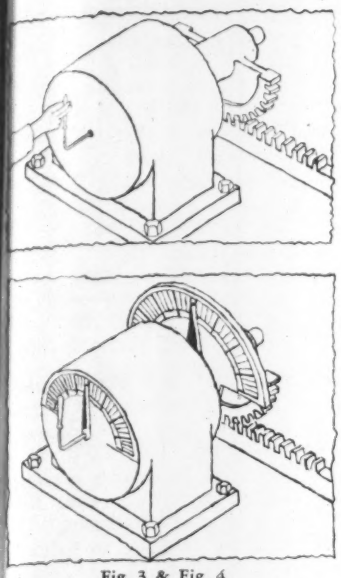


Fig. 3 & Fig. 4

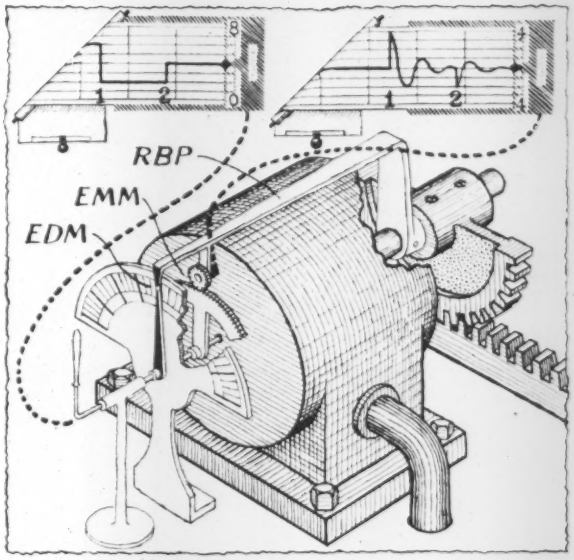


Fig. 5

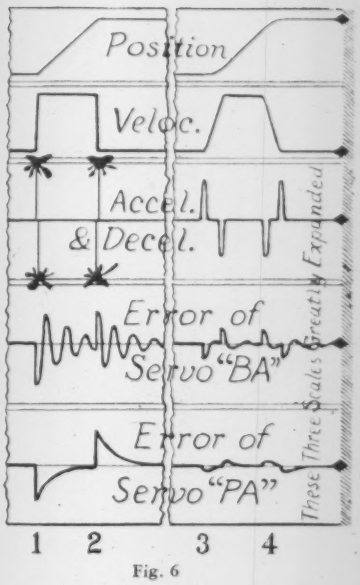


Fig. 6

32 as our point for actuating the jet relays. The point is 21.333 and the time to get there is 10 × √⅔ or 8.1645 seconds. Then, the remaining time, with additive retardation, will be 4.0823 and the total time 12.2468. (See thin solid line curve between dotted and dot-and-dash curves.)

That's what the experts hoped to witness! Not merely a solution but THE OPTIMAL on-and-off solution.

By the way, note that the time to obey your command is 12+ seconds instead of 52 or 53. In industrial automatic-control work this would be a great advantage.

But is there any SM on the market that would give such a performance? Not to our knowledge—and not one of the expert designers we know is giving serious thought to this particular form of ideal solution because it seems to require a higher order of "intelligence" in the "brain-box" of an SM than can be produced for sale at "reasonable" cost on the competitive industrial market. Moreover, various other solutions of the stability problem are embodied in commercially-available devices. The values of various positive and negative accelerations, together with the correct fractions of the desired sudden displacements, do not have to be fed into and worked on by the brains of the commercial SMs in their present physical forms.

So let's consider SMs in their physical forms.

Instead of an aircraft—which combines the power source, the load to be positioned, and various servos—let us consider the simple positioning device shown in Fig. 3. It might not be a servomechanism at all: the "finger-tip" feature might represent an ordinary switch, or an on-off pneumatic or hydraulic relay, or even a mechanical clutch — in which case Fig. 3 would show a *servomotor*, not a servomechanism. The picture doesn't show the LOAD which, as the size of the rack-and-sector suggests, is a heavy one. Let's assume that the load is the heaviest one ever "manufactured"—an ocean liner or a battleship to be steered with precision. We therefore scrap the Fig. 3 servomotor in favor of the device shown in Fig. 4, which a glance is enough to identify as a position-type servomechanism. Now you need not keep your hand at all times on an on-off lever: when you set the input-position lever you know that the output or load position will be the same. You know . . . or you hope! So we provide you in Fig. 4 with a big pointer attached securely to the output shaft to indicate the position of the ship's steering machinery and rudder, not of the ship itself (discussed later). This pointer enables you to verify what you had surmised: that the heavy machinery load (not to mention the ship) cannot follow SUDDEN changes of input signal.

To swing a ship from NNE to SSW in a "jiffy" would not only overload the ship's main power plant: it would overload all the world's power plants.

But we are still at Fig. 4 and you have jiggled the input lever a few times —enough to gain a general impression: a qualitative idea of its response—so now you want some quantitative knowledge—but no higher mathematics!

One thing you learned in moving the lever of the Fig. 4 device is that there was not "feel-back' as there is for example, in aircraft torque amplifiers. You did not feel any drag.

The Fig. 5 servomechanism (don't look at the recorders yet) has been designed for you. Note the repeat-back pointer *RBP*. It, or its equivalent, is an absolute essential of a servomechanism, for every SM must know its own error. (Otherwise it's a mere servomotor.) Note also that the special shape of *RBP* resembles the usual shape of the feedback loop in the usual SM diagram although *RBP* is definitely not a feedback.

You'd be amazed at the mistakes made by experts who use the same graphic symbol for the repeat-back and the feedback and then confuse them although they know that feedback is the feeding of a part of the output ENERGY (or POWER) into the input, whereas repeat-back is an OPEN-ENDED indication.

In Fig. 5 you have so convenient an error-detecting means (*EDM*) that you can use it as an error-measuring means when things don't happen too fast for your eyesight. The true *EMM* consists of a sector-and-pinion and its operation is self-explanatory: it actuates an error-recording instrument having low inertia, like an oscillograph.

The two autographic instruments give you records of INPUT (desired value of the controlled variable) and of ERROR—not of load position (actual value of the controlled variable). At time 1 you have SUDDENLY moved the input lever from 6 to 2; at time 2 you have moved it from 2 to 4 with equal suddenness. There must be a lot of flywheels in the machinery, to judge from the wiggles of the error curve! This machinery includes the servomotor of the Fig. 5 servomechanism. This motor's inertia contributes to the total inertia: little if the SM is hydraulic; much if the SM is electrical (for hydraulic SMs are much livelier in their response).

Now you make two more tests and in Fig. 6 they are recorded by an ideal five-pen recorder.

Knowing that an SM can't follow a sudden-displacement command (infinite velocity) you try a uniform-velocity command (top record: desired position). This means that at time 1 your signal velocity changes from zero to a constant value ALMOST SUDDENLY (note slight off-verticality of velocity record at time 1); and again almost suddenly back to zero at time 2. It means also, at time 1, a "very high" positive acceleration of your input lever immediately followed by a "very high" negative acceleration (those aren't palm trees but ink blots: acceleration-recorder pen hitting the stops); and at time 2 the same rapid sequence in reverse.

You are testing two servomechanisms: one badly adjusted (*BA*); the other properly adjusted (*PA*). Their error curves are what, by this time,

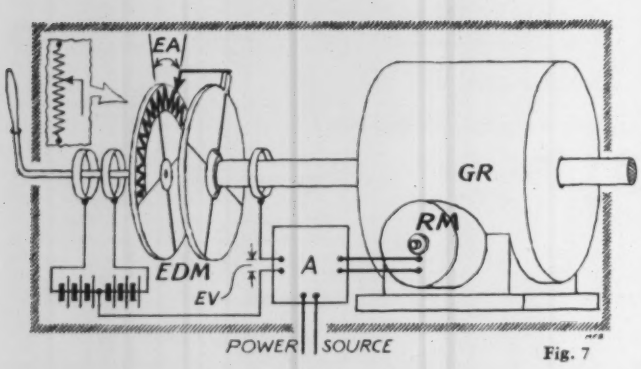


Fig. 7

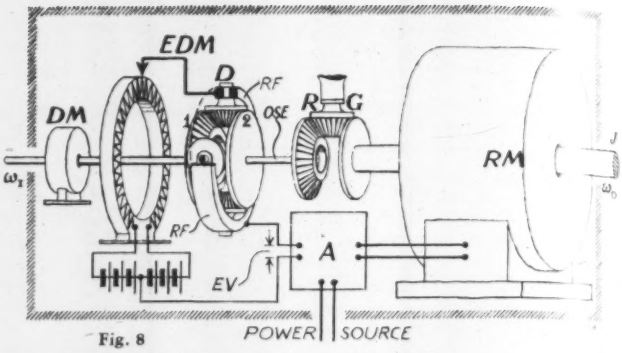


Fig. 8

you expect. Moreover, you discover in the records of this first test a clue to the secret of treating your SM's as well as you treat your own automobile (at least during times of car shortage). Remembering that to keep your car in good condition you start and stop it gently, you resolve to command the load to be accelerated and decelerated gently at the beginning (time 3) and end (time 4) of every displacement input. The five records are self-explanatory but we invite attention to the three expanded chart scales: on an error chart like that of Fig. 5 the errors of the properly-adjusted SM subjected to the second test would be barely visible.

After these allusions to adjustments, it's time for a look at what there is to adjust. One essential of an SM already mentioned is the repeat-back whereby the SM can compare the position of its output shaft (and hence the position of the load if there is no "give" and no slippage) with the position of its input spindle. In Figs. 7 and 8 there is no need of a pointer like the *RBP* of Fig. 5: the output shaft does the job.

In Figs. 7 and 8 the shaded-box symbol signifies that all components of the "chain" between input and output are so ideally shielded that their functions STAY PUT. We thus differentiate an SM diagram from a process-control diagram where (in general) only the desired value stays put and all else is subject to unforeseen disturbances.

Fig. 7 does not show the sector-and-rack which converts the output shaft angle to a linear displacement. We purposely omitted this external detail, for actually the position SM of Fig. 5 is an *angle* SM. In the Fig. 7 SM, the output-shaft angle and the input-spindle angle are compared against each other to give the *error angle EA*.

In the Fig. 7 SM, the error angle *EA* is converted to an error voltage *EV* by an error-detecting means *EDM* which, though not "self-explanatory" to a schoolgirl, need not be explained to you. What we must state explicitly, however, is that if both halves of the battery are equal, if the voltage-dividing resistor is linear and if the slider is at the exact center of this voltage divider when the input-spindle angle and output shaft angle are equal (when $EA = 0$), then *EV* will be exactly proportional to *EA* at all times and its polarity will correspond to the sign of the error.

A little hair-splitting: Another IF is: if the resistances of collector-rings, leads, etc., can be disregarded. Also, "at all times" except when *EA* is so large that the slider would go beyond either end of the voltage-dividing resistor, but this possibility is precluded *in the present example* because the load travel limits are within the error-measuring range: see Fig. 3.

Another fine point: We use the term error-DETECTING means because in many SMs this essential component is a simple high-or-low-or-normal detector; and because it seems to be the term preferred by most SM experts. But there's a trend today among SM writers, toward distinguishing between an *EDM* and an *EMM*.

The error voltage is fed into amplifier *A*. There being long chapters on amplifiers in books you own or can borrow, technical discussions of amplification theories will be skipped. Bear in mind, though, that not all SMs are electrical and that there are ingenious hydraulic, pneumatic and mechanical amplifiers controlling relatively enormous flows of fluid or of energy with exquisite precision. But we have to discuss briefly the NATURE or character of the specific function of box *A* insofar as it affects the over-all performance of the SM. In the Fig. 7 system we can assume linear amplification of power, so that the TORQUE of the high-speed reversing motor *RM* is exactly proportional to *EV* and hence to *EA*. Since *GR* is a gear-reducer unit without slippage or "give," the torque of the output shaft is proportional to *EA* and, of course, in the proper direction to minimize *EA*.

This over-all characteristic of the Fig. 7 SM is a desirable one in most cases. It is far superior to the characteristic of the hypothetical jet'copter SM. Remember? That crude SM simply turned on one jet or the other so that the pull (the acceleration) remained constant while the error was increasing AND ALSO WHILE THE ERROR WAS DECREASING—up to the very moment when the error vanished; but at THAT moment the aircraft had reached its maximal speed so that it overshot. With linear amplification producing torque proportional to error, one improvement has been made toward stability.

It is a great improvement if the load is largely frictional—as are most loads of actual SMs. Suppose, however, that the load is a heavy flywheel on frictionless bearings, and that you insist on commanding a sudden change of position as in Fig. 1. In this case, the slowing-down of a purely inertial load should begin at the half-way point.

The Fig. 8 SM might be called a speed-type SM because its output shaft is not limited to 180° but has to make hundreds or even thousands of turns to displace the load from one extreme position to the other. The *EDM* comprises a differential *D*, which necessitates the use of reversing gear *RG* to make the output shaft extension *OSE* (which drives gear 2) turn in a direction opposite to that of the input spindle (which drives gear 1). Thus the four pinions carried by ring-frame *RF* rotate without revolving when the output shaft angle equals the input-spindle angle (when there is no error). When there is an error angle between input and output, ONE-HALF of this angle is indicated by the ring-frame *RF* and the slider which it carries deviates from the center of the voltage-dividing resistor. The result (assuming a linear resistor) is *EV* proportional to *EA*. Fig. 8 shows the slider at the center, indicating zero error.

Note that the reversing motor *RM* drives the output shaft directly and that an *EA* greater than about 10 radians (573°) cannot be measured and presumably is forbidden. Obviously, this is a high-precision SM and therefore it must be a high-performance SM. It may be called a speed-type SM because, in order to catch a small load position error before it grows big, the output angular velocity must not be allowed to depart for more than "a short time" (relatively speaking) from the input angular velocity. Examine again the three top records of Fig. 6.

So what to do if an operator (not you!) wants to command a sudden change of load position or of load speed, greater than can be obeyed by the motor *RM*, large and powerful though this motor be?

One answer is to PREVENT the operator from doing so, by "flywheeling the input" or by adding the viscous damping means *DM*. Horrifying to some SM experts, this solution satisfies industrial instrument conditions.

For gun-fire control the SM designer MUST provide enough power—and more than enough!—and he can do it because the SM itself is the "process" or most of it; but in industry we find processes with characteristic times and other dynamic characteristics that we can't change or aren't allowed to change. What's more, we often find servomotors specified for us. The *RM* of Fig. 8, though shown inside the shaded-line

border because it is an element of the SM, may have been specified and installed previously. Then, if the input spindle is rotated by the instrument which measures the controlled variable, what's the good of having the commanding output of this measuring instrument (the SM input) undamped?

The crux of the matter is that the damping ratio of *DM* must not result in accelerating the output less than if there were no damping. This criterion can easily be met, as may be shown by the aircraft analogy (disregarding air drag): Jet A can accelerate this aircraft by so many *G*'s and no more. Therefore it can fly from 0 to 16 in so many seconds and no less and, retarded by jet B, from 16 to 32 in the same number of seconds. This is its maximal performance. We have already seen that shifting the radio beam suddenly from 0 to 32 produces wild oscillations and that the top performance can be obtained by positioning the beam at 16. But why position it at 16 *suddenly?* Just keep the beam ahead of the aircraft; jet A will deliver its full power as long as it lags the beam, whether by a foot or by a furlong. Next, imagine this aircraft-control system modified so that the power of each jet is proportional to the error, with a "proportional band" or "throttling range" of 20 yards (10 yards on each side of zero error). Displacing the beam at such a rate that it will be 50 yards ahead will have no more effect than keeping it 10.001 yards ahead. This can be accomplished by damping the control-tower device, so that the beam will never be more than 10.001 yards ahead!

Another reason why input damping contributes to system performance is that IT PREVENTS SUDDEN-STOP COMMANDS.

(An SM may be TOO GOOD for a specific job. For example its frequency spectrum may be so broad that its designer may have to filter out an objectionable band of relatively high input frequencies.)

Viscous damping of measuring elements is common practice. The optimal value depends on the various physical constants involved (at one extreme a river-stage gage, at the other a direct-writing oscillograph). Practically all electrical indicating instruments have their moving elements damped.

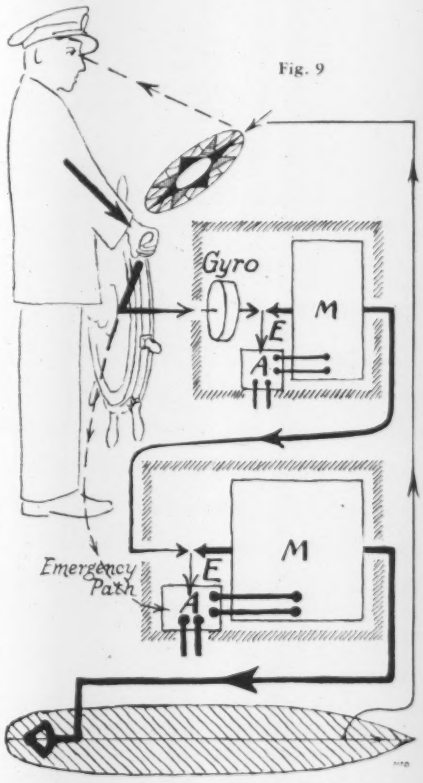
The *DM* of Fig. 8 is utterly superfluous, undesirable—and, in some cases badly detrimental—if the measuring element (whose output is the SM input) already suffers from serious lag.

Now let us consider "the brains of the servo."

In the position-type and speed-type electrically-powered SMs, Figs. 7 and 8, the amplifier *A* may be of various degrees of complexity—from a single electron tube to an elaborate assembly. In the latter case, *A* may resemble an instrument and it may be manufactured by an instrument company; it may be even referred to as "an instrument" without causing any confusion. Simple or complex though its design and construction may be, its *function* is that of a valve: to control a flow-rate—not the flow-rate of a fluid but the flow-rate of electric energy. This is its *essential* function.

It is also the essential function of many non-automatic electrical devices known as "controllers" (examples, a manually-operated trolley-car "controller," a machine-tool motor "controller," etc.). So it came about that the electrically-trained designers of electrical SMs adopted the common electrical-engineering terms controller or control for the element which, *at the command of a measuring element*, performs the function of a valve and, in its simplest form, is a mere valve (a thyratron or a vacuum tube). It is perfectly true, however, that in its more elaborate forms this element performs analytical functions of a high order—performs the equivalent of mathematical operations almost instantaneously and absolutely automatically. Then it becomes a true "instrument"—still not an automatic controller in the Instrumentation sense but an automatic instrument deserving to be called an "electrical brain" rather than a "valve," a "control" or even a "controller." There may be complete SMs in the *A* box to make the main SM work right.

Fig. 9



The high order and the importance of the functions which this element performs in highly-developed SMs (such as some used on battleships) can be brought out by using the aircraft analogy again. For best performance in flying from 0 to 32 (disregarding air drag) it should be made to accelerate from 0 to 16 and to decelerate from 16 to 32. This means top speed at 16. But the error is the distance from 32 at any moment and the rate-of-decrease of the error is the velocity of the aircraft. Therefore, for best performance, the rate-of-decrease of the error should be highest at 16. Now we can apply this idea to the Fig. 7 SM so that even a sudden command to displace the load from one end of the scale to the middle will be obeyed without an equal overshoot—without any overshoot at all: Amplifier *A* contains a network which measures the rate-of-change of the error voltage* and throws the switch at the mid-point of the input's sudden displacement (if friction is negligible) or a little beyond the mid-point, causing the servomotor and flywheel-type load to stop accelerating and start decelerating at THIS point: the mid-point of the signal value or in this case one-quarter of the total positioning range.

The last ten words of the foregoing paragraph indicate that the PARTICULAR control action described is ideal for only one value of a sudden-displacement input. If half that displacement is commanded, the rate-measuring element will not snap the motor-and-load from acceleration to deceleration until the load reaches the desired position; sustained oscillations would then result.

In practice this on-off action is seldom used. The amplifier instrument converts the error-rate into a PROPORTIONAL ACCELERATION—positive or negative as required. This control action cannot be IDEAL for all values of a sudden-displacement commands but it is GOOD for all values and it can be adjusted for the average value. But sudden changes of position are uncommon. Oftener met in practice are relatively sudden changes of input velocity, like the top records of Fig. 6; and for such conditions this mode of control contributes greatly toward stability.

This mode of control is variously known as derivative, rate response, rate action, error-rate damping, etc.

Another way an amplifier can handle *EV* is to totalize its instantaneous values—to meter it or to integrate it, as a watthour meter integrates electric energy—and command the servomotor accordingly. This is especially important in speed control and the example that suggests itself is frequency-control corrections in central stations that supply electric time: In the early-morning hours an operator observes the ACCUMULATED error—the INTEGRAL—the AREA between the day's frequency record and the standard-frequency line (or in most cases the algebraic sums of the areas above and below). This error integral is easily observed: it is the error of the clocks on the line. Then he applies a correction whose area or integral is equal and opposite. (He does it over a relatively long time interval, such as a quarter-hour, so that people will not notice; if he did it in a brief interval, suddenly, the frequency change would be a nuisance.) This is known as metering control, integral control, etc.

Numerous other modes of control can be produced by highly-developed amplifiers. Modes of control are BEHAVIORS and their number is infinite—like the

*In non-electrical SMs the element which measures rate-of-change of error may take various forms, including one resembling an airplane rate-of-climb meter.

Note that if this were done physically it would lead to non-linearities and possible instability.

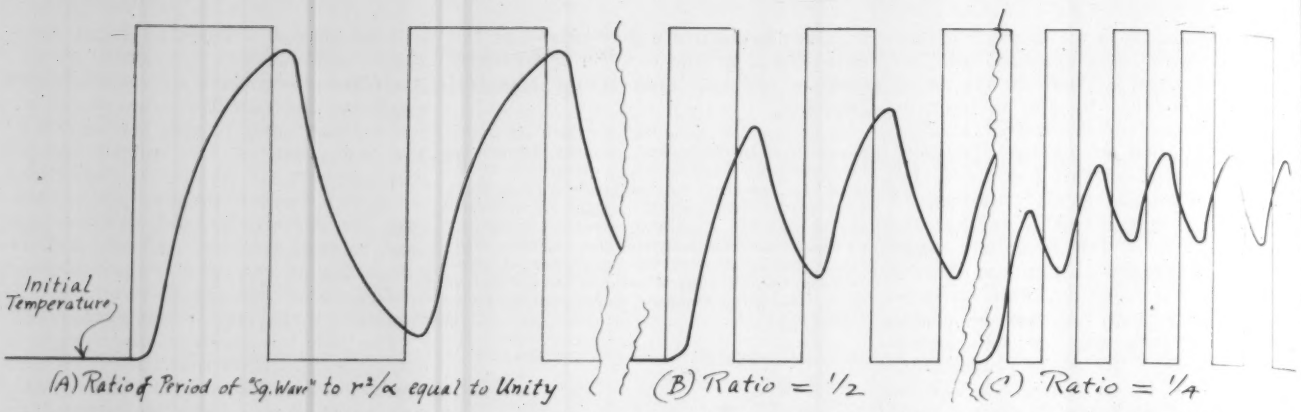
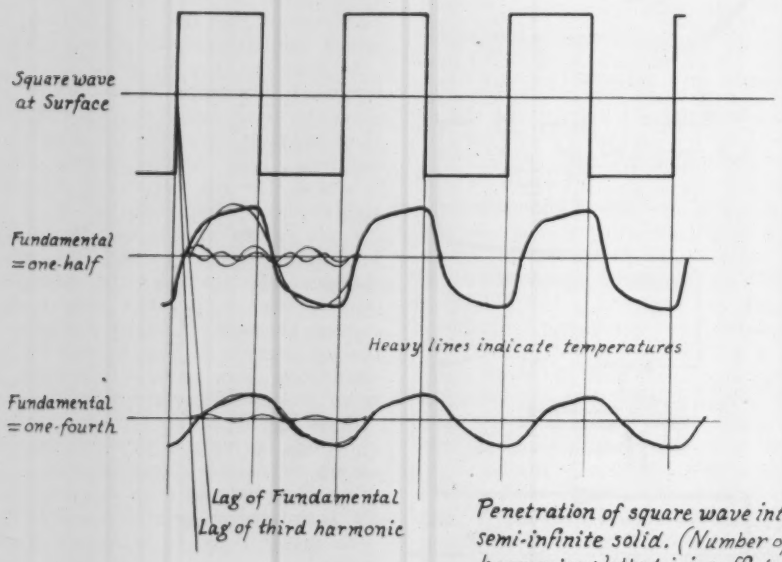
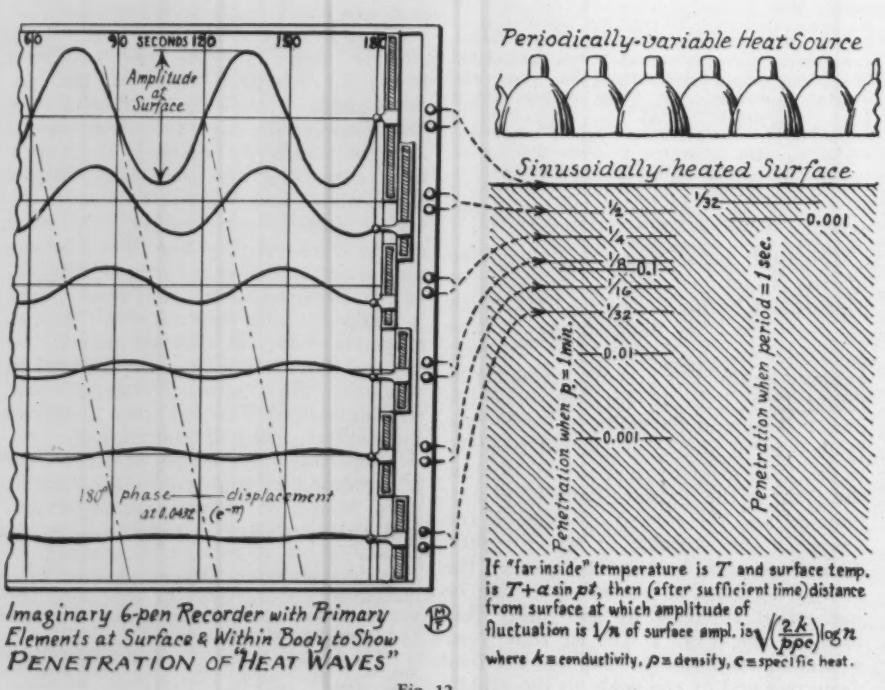

Initial Temperature
(A) Ratio of Period of "Sq. Wave" to r^2/α equal to Unity
(B) Ratio = 1/2
(C) Ratio = 1/4
Temperatures at axis of Cylinder ($\frac{\alpha}{r^2}$ relatively low) whose surface is subjected to "square-wave" temperature fluctuation

Fig. 10



Penetration of square wave into semi-infinite solid. (Number of harmonics plotted is insufficient for "line width" accuracy.)

Fig. 11


60
90 SECONDS 120
150
180
Amplitude at Surface
180° phase displacement at 1.0472 (e^-π)
Periodically-variable Heat Source
Sinusoidally-heated Surface
1/2
1/4
1/8
1/16
1/32
1/32
0.001
0.1
0.01
0.001
Penetration when P = 1 min.
Penetration when period = 1 sec.
If "far inside" temperature is T and surface temp. is T + α sin pt, then (after sufficient time) distance from surface at which amplitude of fluctuation is 1/n of surface ampl. is $\sqrt{\left(\frac{2k}{ppc}\right)}\log n$
where k = conductivity, ρ = density, c = specific heat.

Imaginary 6-pen Recorder with Primary Elements at Surface & Within Body to Show PENETRATION OF "HEAT WAVES"

Fig. 12

different behaviors of a human being. We have dealt elsewhere with this subject and its discussion could run to book-length if not cut off to deal once more with an important distinction.

A servomechanism is, in itself, a form of automatic-control system, but not all automatic-control systems are SMs. In fact, one automatic-control system may comprise one SM, or even a plurality of SMs, AMONG ITS OTHER ELEMENTS. In most industrial automatic-control installations THE PRIMARY MEASURING ELEMENT is the real master; so that the study of its characteristics is in most cases the most important study for the control-instrument USER to make.

Instead of elaborating this argument and adducing a proof by ten pages of text—a proof which some of our friends will refute by twenty pages of text and new equations beyond our feeble ken—we have drawn Fig. 9 which conveys our main points. The primary measuring element—the "master" in more ways than one—is a human being. Note that each SM has its own repeat-back. Note that there is no feedback* (none SHOWN, though the energy feedback or power feedback principle may be utilized in the *A* of either SM). Note that the most important repeat-back* goes to the master and only to the master, so that only the master knows at all times the most important error, namely the departure of the ship from the set course. Note how an output can become an input. Note other things, then take out your sketch-pad and draw other circuits—which should be easy because this one is quite unorthodox and because the elements shown can be combined into many different ways!

Important as is the master (and from his looks in Fig. 9 a healthy youngster with rapid reflexes and perfect coordination) he often suffers from serious lag or sluggishness in practical industrial applications.

The inherent lag of many forms of

*Dashed-line repeat-back from compass to master's eye signifies open loop, but if a pick-up and prime relay were substituted for the human being we would have an AUTOMATIC-CONTROL SYSTEM with the compass (reset periodically by hand according to latest reports of magnetic variations) resetting the gyroscopic compass.

measuring elements is most obvious in batch processes but, since "sluggishness" is relative, it may be averred that the saying "all thermometers show what the temperature WAS—not what it IS" can be extended to all measurements of variables. Yes, even to non-variables such as dimensions. Example, the feeler element of a contour-machining SM when it comes to a square shoulder.

From a square shoulder in a master pattern, and the specific example of machine-tool control, let us generalize: THE SUPREME TEST OF AN AUTOMATIC-CONTROL SYSTEM IS A SQUARE WAVE DISTURBANCE WITH A PERIOD OF THE SAME ORDER AS THE PRINCIPAL CHARACTERISTIC TIMES OF THE APPLICATION (the application may be a process, a machine or a circuit).

Anyone who claims that square-wave disturbances are not found in practice should insert a bare-wire fine-wire couple in a small heat-treating furnace in use and, before the couple is destroyed, observe the effect of opening and closing the door and compare it with the record produced by the heavily-protected couple hooked up to the recording controller. The fact that the square-wave disturbance is NOT EXTREME (not from room temperature to top furnace temperature) is trivial; the important facts are that the disturbance is a series of square corners and that the working couple doesn't feel them. Result, the proverbial combination of "straight-line record but lots of spoilage" and the old accusation, "The recorder is a liar."

This sluggishness is inevitable; it springs from the laws of Mother Nature, even the fine-wire couple is a fibber! Fig. 10, 11 and 12 are designed to bring out some of the underlying principles, which are to be found in only a few treatises and only in mathematics beyond the grasp of most engineers other than recent graduates.

If you know the thermal diffusivity of a protection-tube material, Fig. 10 will give you within ±10% the response curve of the element inside it to a sudden change of ambient temperature. Assume that the tube is a solid cylinder of half its actual radius, use plain arithmetic and copy the first part of the curve: this "delayed start" is what affects control.

Fig. 11 shows the connection between attenuation and lag. An element which is insensitive and slow will give its commands "too little and too late." With such an element, adding a derivative-action gadget to the controller may worsen the hunting instead of curing it.

As a bow to the advocates of the sinoidal-input analysis, Fig. 12 shows how a heavily-protected temperature-measuring device may cause the control elements which it commands to do the wrong thing at the wrong time.

It all goes to show that the master entity of an automatic control system is not so much the tangible primary element as the INDICATION of this element. "The proper performance of an automatic controller depends . . . upon the correctness and TIMELINESS of the information it receives": this slogan should, after seventeen years of reiteration, make users scrap not only poorly-calibrated elements but slow elements, because nothing is truer than the other old slogan: "Dead Times Mean Dead Zones." Therefore, STUDY YOUR RESPONSE CURVES! The usual response curve is S-shaped, with a slow start" too often unsuspected.

Acknowledgments.—This article has been shown in proof form to the following, whose suggestions leading to alterations are gratefully acknowledged: Donald Campbell, M.I.T.; Allen Chaplin, Johns Hopkins Univ.; Winfield Heinz, Calco Chem. Co.; R. W. Jones, Northwestern Univ.; C. E. Mason, Bristol Co.

The Frequency-response Method of Control Analysis

By WILLIAM C. MOOG*, Cornell Aeronautical Laboratory, Buffalo, N. Y.

IN the recently-developed frequency-response method of analysis, the engineer interested in automatic control can find a simple, effective and powerful tool to assist him in synthesizing and rationalizing control systems. In many respects the method may be considered analogous to the use of logarithms in the solution of numerical problems, for it is also essentially a transformation. Furthermore, as is true in the case of logarithms, it is not necessary that one understands the basic theory in order to intelligently apply the method. This is a particularly fortunate circumstance, for the mathematics of frequency-response procedure is but algebraic and graphical in character. Proof of the theory, on the other hand, is necessarily written in the language of the calculus of the complex variable, a level of mathematics beyond the scope of the majority of engineers engaged in the automatic-control field.

It is the purpose of this article to introduce the method as an analysis tool to those who are unfamiliar with it. The subject-matter will therefore be confined to procedures associated with practical application of the method.

As a first consideration, it is proper to deal with the nature of the fundamental equation of automatic control, for it constitutes the framework of analysis techniques. The components of this equation will then be related to a simple, typical control system and the method of resolving them in the form

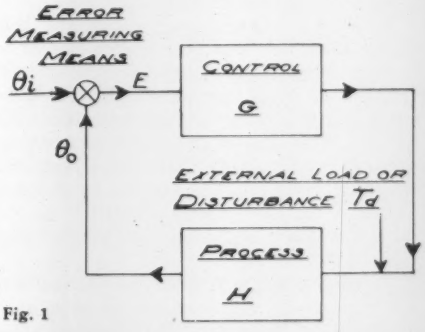


Fig. 1

of frequency-response diagrams by experimental procedures will be demonstrated. These curves will then be combined to form the system curve and it will be interpreted to give information concerning SYSTEM STABILITY, RESPONSE AND STEADY-STATE ERROR. The same component curves will then be developed mathematically in terms of the physical constants of the system. Finally, modifications of the typical system to illustrate the effects of integral and derivative components will be discussed, together with other topics associated with application of the method.

Referring to the block diagram of a single-loop closed-cycle system, shown in Fig. 1, symbol θ_i represents the selected value of the controlled variable and θ_o its actual value. At the system error-measuring means ⊗ these values are compared, any difference resulting as a proportional error signal E. Thus:

$$E = \theta_i - \theta_o \qquad (1)$$

This equation might represent, for example, a measuring element of a furnace temperature controller† where θ_i is the desired temperature, θ_o the actual furnace temperature and E the measuring-element *"output"* (voltage, deflection, etc.) *proportional at every instant to the difference between these temperatures.*

The output-input ratio or TRANSFER FUNCTION of the control unit is represented by G, which therefore describes

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†EDITOR'S NOTE.—The author has finally persuaded us to let him use this temperature-control example, but our duty to *Instruments* subscribers compels us to remark that practically all furnace temperature control systems comprise a measuring system, a servomechanism commanded by the measuring system, and other components; so that the servomechanism is only a part of the controller which itself is only a part of the closed-loop dynamic system consisting of "controller" and "application." For studying and improving furnace temperature control systems, transient analysis is said by some authorities to be more convenient than frequency analysis.—M. F. BEHAR

the over-all action of the unit. The transfer function of the process or machine under control is represented by H. Symbol T_d designates an external system load or disturbance. These values may be combined, according to their definitions and the sense of the diagram, in the relationship:

$$\theta_o = EGH + T_dH \qquad (2)$$

Using the same example, G would represent the heat output of the furnace heating element relative to the error signal, H the relationship of actual furnace temperature to the heat applied, and T_d the effect of load, for instance the heat loss resulting from a partly open furnace door. In words, the equation states that the actual temperature is equal to the heat applied ($EG - T_d$) times the ratio of temperature to heat applied (H). It will be recognized that in applying equation (2) to this example, the sign of T_d itself is negative.

Combining equations (1) and (2) and solving for the actual value of the controlled variable relative to its selected value and external disturbance, we determine the fundamental equation:

$$\theta_o = \theta_i GH/(1+GH) + T_dH/(1+GH) \qquad (3)$$

It will now be convenient to make a distinction between an *automatic controller* and a *servomechanism*, although it is to be understood that these definitions are neither universally recognized nor always applicable to a particular system. An *automatic controller* (or automatic-control system) is the form of control used where the selected value of the variable is essentially a constant but the system is subject to external and variable disturbing influences. The majority of processes and industrial applications typify control of this nature. A *servomechanism* on the other hand is used where the external disturbance is essentially a constant but the selected value of the variable is subject to change. Gun-fire control may be given as an example, because the load (torque required to move the gun) is assumed to be a constant but the gun must follow a variable input signal.

Utilizing the principle of superposition, we may now consider the fundamental equation of a *servomechanism* as:

$$\theta_o/\theta_i = GH/(1+GH) \qquad (4)$$

for, as T_d is a constant, it will not affect *variation* of θ_o relative to θ_i. Likewise the equation of an *automatic-control system* may be considered as:

$$\theta_o/T_d = H/(1+GH) \qquad (5)$$

Those familiar with the theory of electronic amplifiers may note the similarity of these equations to the basic equation of the feedback amplifier. This analogy is of considerable interest, for the method of frequency response is a direct adaptation of the criterion developed by Nyquist for the amplifier problem.

Having developed the system equations, it is now necessary that we investigate the nature of the transfer functions G and H. These functions will of course depend upon the particular system concerned and this, for our purposes, will be the one shown in Fig. 2. The dashed lines of the drawing distinguish the various components in accordance with the block diagram, Fig. 1. This system is one containing a direct-coupled steam-turbine-driven generator having the load resistance Z. The controlled variable θ_o is generator speed, which is to be maintained at every instant at the selected value θ_i by a hydraulic servomotor.

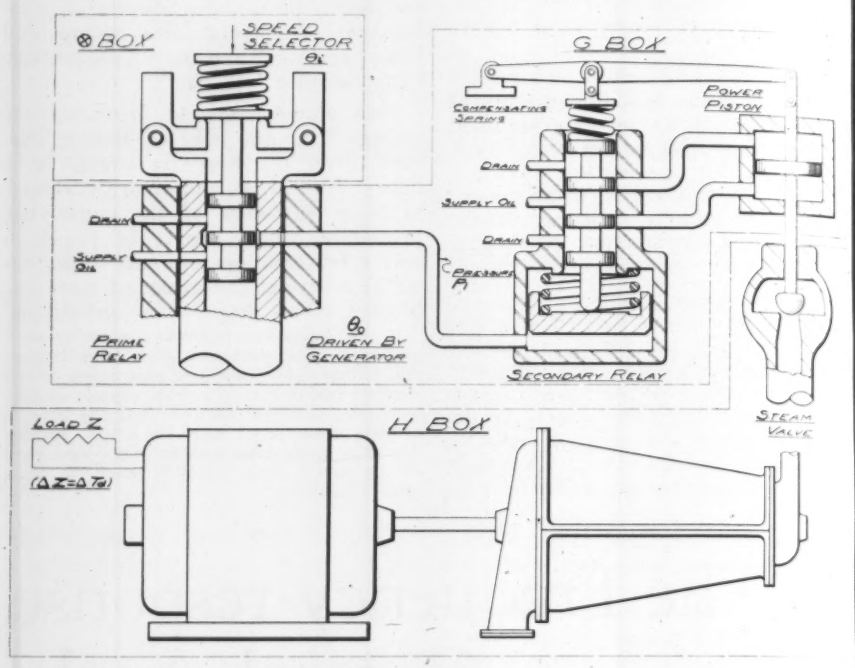


Fig. 2

For our purpose—to illustrate the usefulness of the frequency-response method—we shall study the system reactions as θ_i is varied, the load resistance Z remaining constant at its rated value. Thus the servomechanism equation (4) will apply. (Had we been interested rather in the system properties relative to load change with θ_i to be kept constant, equation (5) would have been used.)

In analyzing a system by the method of frequency response, it is desirable that the various transfer functions be expressed as non-dimensional ratios. This can be done for the typical example by the use of speed as the unit of measure. The procedure will be demonstrated as the various system components are discussed.

The selected value of speed is determined by the loading of the governor spring. The governor shaft is driven by the generator and the flyweights then develop a force which is a function of the actual speed. Any unbalance of these forces results in a deflection of the governor pilot valve proportional to the error. It will be evident that this deflection may then be expressed in units of speed rather than distance.

Transfer function H relates actual system speed to steam valve position. We shall assume that the generator output voltage is a linear* function of the speed and that the generator load torque is likewise a linear function of the speed; also that the steam admission valve is properly contoured to develop linear steam flow relative to valve lift. With the load resistance Z fixed at its rated value, then the process load torque will be directly a function of the actual system speed. The applied torque is assumed to be a linear function of steam flow, or of valve position. At equilibrium conditions, these torques must balance and it can therefore be stated that each position of the valve may be expressed as equivalent selected speed and the process output-input ratio, as the ratio of speeds, will be non-dimensional.

Transfer function G describes motion of the steam valve relative to governor valve position. Both of these motions may be expressed in terms of equivalent speed, as previously shown, and the control output-input ratio will then be non-dimensional. The external disturbance T_d may be defined as the change in load torque due to change of the load resistance Z from its rated value. In this analysis, however, Z has been assumed a constant and T_d will therefore be zero.

The experimental procedures used to determine frequency-response diagrams require that a sinusoidal motion or oscillation of constant amplitude be applied to the input of the transfer function. The output response is then measured for various values of frequency.

*Non-linearities are treated later.

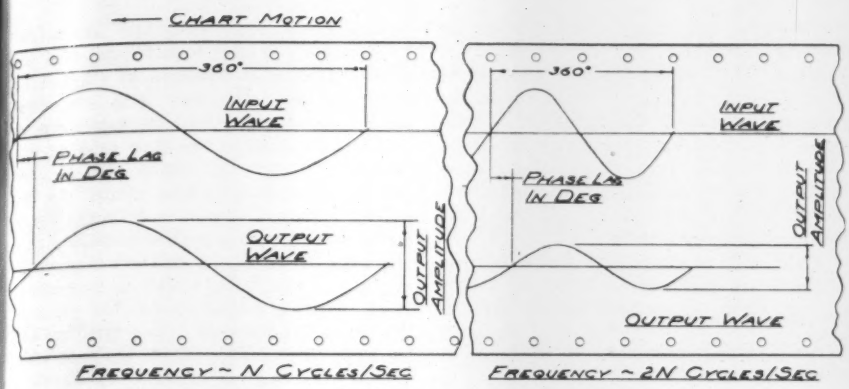


Fig. 3

permitting the output-input ratio to be determined as a function of frequency.

Suppose now that harmonic motion, that is, a sinusoidal input, of constant amplitude be applied to the steam valve. (The amplitude is unimportant, provided of course that it be somewhere within the working range of the valve.) as shown in Fig. 3. At a frequency of N cycles per second we may directly measure the phase lag in degrees, for the length of one cycle provides us with a scale of 360°. As the frequency is increased to $2N$ cycles per second, it will be noted that the output amplitude diminishes. Conversely, if the frequency were decreased, the amplitude would increase, reaching its limiting value at zero frequency. The zero-frequency amplitude may be easily determined by measuring the speed difference between fixed valve positions of maximum and minimum input amplitude. Now, as zero frequency and equilibrium are synonymous conditions, then at zero frequency the output-input ratio must have the value one, for actual speed then equals valve equilibrium speed. At higher frequencies the input amplitude remains constant but the output decreases, and thus *the ratio of output amplitude at a particular frequency to the zero-frequency amplitude is the transfer function output-input ratio at that frequency.*

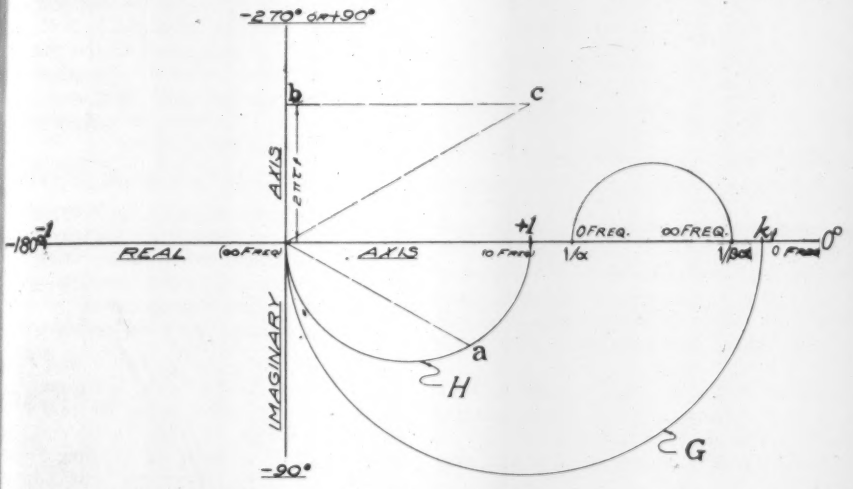


Fig. 4

It will not be difficult to realize that as the frequency of oscillation of the valve increases, the amplitude of speed change will diminish by reason of the inertia of the machine. Certainly, if the valve is moved very rapidly, the system speed will be determined as the value corresponding to the average amount of steam passing through the valve. It will also be true, but perhaps not quite so evident, that the speed change will have a phase lag relative to the input.

Recalling now the fact that there is a corresponding value of equilibrium speed for each valve position, the phase lag may be explained in this manner: If, as the valve passes through its position of maximum amplitude, the speed has not yet reached the corresponding equilibrium value, it will continue to increase as the valve closes. This difference in direction will persist until the valve equilibrium speed and the actual system speed coincide. The time difference in the peak values of the two representative curves is a measure of the phase lag.

Suppose that we have made a strip-chart record of valve position and speed for various input-sinusoid frequencies

Referring now to Fig. 4, a point (a) may be plotted, representing frequency N, where ITS VECTOR LENGTH IS THE AMPLITUDE RATIO AND ITS ANGLE IS THE PHASE LAG. Continuing this process for various frequencies, we may then develop the frequency locus curve, H, of Fig. 4, for the entire frequency spectrum from zero to infinity. In practice, however, frequencies above ten cycles per second need not be considered, for few systems exhibit significant response beyond this range.

If the control is examined in a similar fashion by oscillating the governor pilot valve and measuring steam valve position, the G curve of Fig. 4 will be obtained. This curve differs in one important detail from the process curve H; the zero frequency intercept is no longer one but some value k_1. This value may be termed the CONTROL GAIN. It is of course equal to the zero-frequency ratio of steam-valve position change to governor-valve position change when both are expressed in units of speed.

Combining the G and H curves at points of common frequency by multiplication of vector length and addition of angle, we determine the system GH curve, I of Fig. 5. Now we can apply the stability criterion which, for unconditionally stable systems, simply states that IF THE NEGATIVE REAL AXIS IS INTERCEPTED BY THE GH CURVE, THIS INTERSECTION MUST OCCUR BETWEEN MINUS ONE AND ZERO.

The system GH curve might also have been determined directly by oscillating the governor valve and measuring system speed. It has been developed as the product of two transfer functions

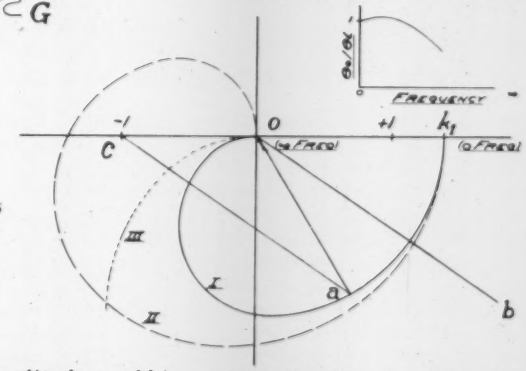


Fig. 5

primarily for simplicity of presentation. However, this approach will also serve to illustrate one of the advantages of frequency-response analysis — the fact that system components may be individually studied and the resultant data easily combined to form the system solution.

The point minus one has considerable significance in the method of frequency response. We may explain it physically in the following manner: At the system error measuring means ⊗ we introduced what in effect was a 180° phase shift. That is, if the error for instance was increasing, the signal applied to the control was to decrease the error. If

these signals be plotted as sine waves, their ordinates will be equal but opposite, indicating a 180° phase difference. Now at the point of intersection of the *GH* curve with the negative real axis, another 180° lag has been added, resulting in a transmission of a 360° lag through the closed loop and this will be recognized as a complete cycle. Now, if any spontaneous oscillation appears in the system (such disturbances may arise from a variety of causes) it will be self-perpetuating for, as each cycle proceeds around the closed loop, it continuously forms the input for the following cycle.

If the value of the *GH* intercept has the value minus one, the cycle as it traverses the loop will remain constant in amplitude. If it is greater than minus one, each cycle will be greater than the one preceding by approximately the value of the intercept. This condition will of course be recognized as an unstable system. If, on the other hand, the value of the intercept be less than minus one, oscillations will be attenuated and the system will be stable. This explanation of minus one is hardly rigorous. It may help, however, to give a general understanding of the significance of the point.

It will be evident, therefore, that if the system is stable, the proximity of the *GH* curve to the point minus one will determine the manner in which the system damps transients. This proximity may be best expressed as the θ_o/θ_i ratio. Since this ratio, from (4), is $GH/(1+GH)$, we can determine it as a function of frequency by geometry. Vector **(oa)** is *GH* and **(ob)** is $1+GH$. But **(ob)** is also equal to **(ca)**. Hence the ratio **(oa)**/**(ca)** is equal to θ_o/θ_i. In Fig. 5 it is shown plotted as a function of frequency. For high-performance systems this ratio generally has a maximum value of 1.2 to 1.3, corresponding to a transient response slightly more oscillatory than the critically damped case. By critical damping we mean, of course, that the system most quickly reaches a new value with no overshoot. Usually it does not represent the most desirable performance, for slight overshoot is negligible and the new value is then more quickly attained. The frequency at which the θ_o/θ_i curve reaches its peak determines speed of response and should therefore occur at as high a value as is consistent with other requirements. As these standards are empirical, however, no one value can be selected as the ideal for all systems. Rather they must be determined to fit the particular type system concerned.

Equations (1) and (2) may also be combined to form an expression for the system error (sometimes called "regulation" or "droop"):

$$E=\theta_i/(1+GH)-T_aH/(1+GH) \qquad (6)$$

In the steady state the input frequency to the system will be zero and the value of *GH* will be simply the gain k_1. Obviously then, the higher the gain, the smaller will be the error. Yet as the gain is increased, the *GH* curve is expanded (III of Fig. 5) increasing proximity to minus one and thus decreasing transient attenuation. A compromise is therefore necessary in selecting the proper gain unless the control be modified. We shall discuss such modifications after we have analyzed the system mathematically.

From the assumptions made for the process, we can express the load torque as $k_2\theta_o$ where k_2 is load torque per unit speed. The applied torque, a function of steam flow, is k_3y where k_3 is torque per unit valve travel and y is steam valve deflection. Equating these terms and including the inertial reaction of the machine, $J\ d\theta_o/dt$, where J is the moment of inertia, we develop the expression for the process:

$$k_3y=k_2\theta_o+J\ d\theta_o/dt \qquad (7)$$

Replacing d/dt by the operator p (where $p=d/dt$, $p^2=d^2/dt^2$, $p^{-1}=\int dt$, ...), and simplifying:

$$k_3y/k_2=\theta_o\ (1+pJ/k_2)$$

In standard units, J is lb. ft. sec.^{2} and k_1 is lb.ft.sec., so that the ratio J/k_2 has units of time and may be replaced by the process characteristic time or "time constant" T_1. Following any instantaneous steam valve position change, T_1 is equal to the time required for the speed to reach 63% of its new value. The concept of time constants is a familiar one in electrical engineering, and the concept of characteristic times is useful in mechanical problems of this type. We may note that these times are dependent only upon the physical constants of the system.

The value k_3y/k_2 will have units of speed, and we may replace it by n. Thus the final value of the transfer function becomes:

$$\theta_o/n=1/(1+pT_1) \qquad (8)$$

Replacing p by its equivalent $j\omega$ where j is the square root of minus one and ω is angular velocity, then replacing ω by $2\pi f$ where f is frequency in cycles per second, the transfer function becomes:

$$\theta_o/n=1/(1+2j\pi fT_1)$$

Now we have an expression in complex numbers with the only variable that of frequency. Solving and plotting in accordance with usual procedure* we again develop the locus curve of Fig. 4. A sample point will be located to illustrate possible procedure. The value $2\pi fT_1$ is computed for a particular frequency and plotted on the positive j axis as point **(b)**. To it is added the value one, resulting in point **(c)**. One divided by **(c)** becomes **(a)**. (Angular subtraction, length division).

The primary element of the control unit measures speed error, and the prime relay thus develops an output pressure P_1 which is a function of the error. The pilot valve is of single-land construction with the land somewhat smaller in width than its mating port. Two valve orifices are thus created, one between supply pressure and P_1, the other between P_1 and drain. As the valve is moved, these orifices change in area and the areas of course are the directly a function of valve position. Equating the flow, which is common to both orifices, we can solve for pressure P_1 as a function of valve position and supply pressure. The characteristic curve of this type of valve is shown in Fig. 6. At its mid-range the curve is essentially linear and the control will be adjusted so that the valve is centered when the speed error is zero. We may therefore express P_1 as a linear function of the speed error. Thus:

$$P_1=k_4E \qquad (9)$$

where k_4 equals pressure per unit speed error. As P_1 is vented to an essentially dead-end system, negligible lag will be introduced as it is changed.

Pressure P_1 is applied to the piston of the secondary relay in opposition to the piston spring and compensating spring forces. Denoting secondary pilot valve deflection by x, then:

$$x=(P_1A-k_5y)/k_6 \qquad (10)$$

where A=Piston Area,
k_5=Compensating spring rate times lever ratio,
k_6=Compensating spring plus piston spring rates,
y=Steam valve deflection.

The secondary pilot valve has two lands whose widths equal their mating ports. As it is moved from its centered position, valve orifices are created which permit a path of oil flow from supply pressure, through the power piston chamber, to drain. This flow is directly a function of the orifice areas or valve position. Hence, as the piston velocity is a function of the oil flow rate:

$$x=T_2\ dy/dt \qquad (11)$$

where T_2 is the secondary relay time constant, $A_1/(cW\sqrt{2gh})$.
A_1=Power piston area,
c =Orifice coefficient of discharge,
W =Circumferential length of pilot valve port,
g =Gravitational constant,
h =Fluid head equivalent to one-half supply pressure.

Combining equations (9), (10) and (11) and replacing y by nk_2/k_3 [this equality was used in developing equation (8)] the final value of the control transfer function becomes:

$$n/E=k_1/(1+pT_3) \qquad (12)$$

where $k_1=k_3k_4A/k_2k_5$
$T_3=k_6T_2/k_5$

In units, the value of k_1 is non-dimensional and is again the control gain. T_3 has units of time and is the control time constant.

*The algebra of imaginary or complex quantities is treated in the majority of engineering handbooks and standard a-c electrical texts. For instance *Marks Mechanical Engineers' Handbook.*

Fig. 6

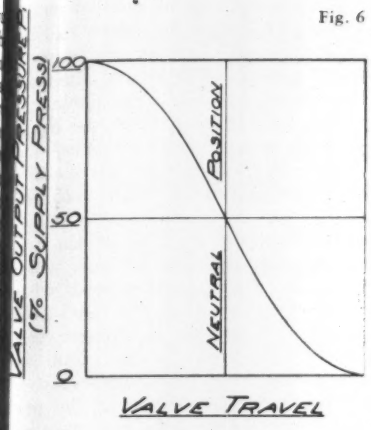
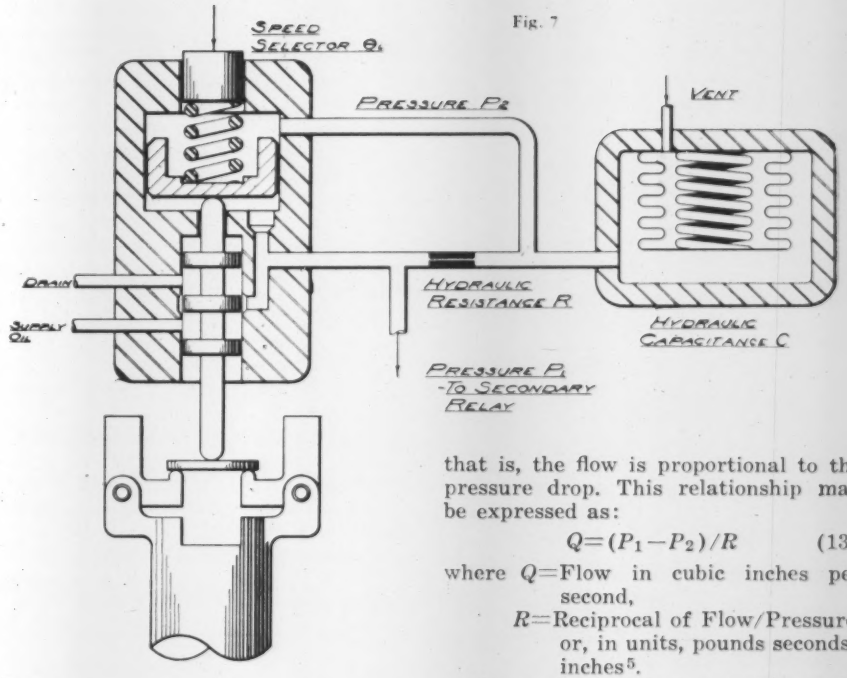


Fig. 7



The mode of control considered up to now is that whereby the corrective action is proportional to the error. (Some call it "droop" control or "regulation.") The control unit has this characteristic by virtue of the compensating spring which returns a measure of the control output to reset the input, effectively requiring therefore a definite error for each output piston position. Operation of this form of control unit is quite easy to visualize in terms of frequency response, for changes in the amount of compensation (k_8, change both the control gain (k_1) and the time constant (T_3). If the compensation is increased by stiffening the compensating spring or increasing the lever ratio, the gain and time constant are both made smaller. A smaller time constant decreases phase lag and both factors thus reduce proximity of the GH curve to minus one. This, as has been previously mentioned, helps when problems of stability are paramount. The mitigating feature of this change is the increased steady-state error sensitivity to load change, for k_1 is the value of the zero-frequency GH intercept. [See equation (6)].

Often a problem requires a mode of control which introduces no error or "droop" as the control point or load is changed. This may be accomplished if the corrective action contains a term which is proportional to the integral of the error. Our control unit may be changed to this mode of control by elimination of the compensating spring. Now the power piston velocity is directly a function of the error, or, what is the same thing, its position is equivalent to the integral of the error signal. The control transfer function will be of the form K/pT. In the steady state the input frequency is zero and thus p is zero. Hence the value of G is infinite and from equation (6) the error will be zero. The locus of the transfer function is the negative j axis; and therefore, as a 90° phase lag is introduced at all frequencies, problems of stability and response are intensified.

In our discussion, we have considered only the effects of two system lags. Obviously, in any practical system such an assumption is overly optimistic. In our system, for example, lags will be introduced by the inductance of the generator windings and by capacity in the steam line between the admission valve and turbine. Each of these lags will have a transfer function which affects the GH curve. In the case of those mentioned, however, the transmission will be effectively unity and the phase shift correspondingly small at the frequency band of the system near the minus one point. Therefore they will not noticeably affect the analysis.

Let us assume, however, that these lags are large, or that a third lag of major proportion is introduced in the system. The GH curve may then take the form of curve II of Fig. 5. If we are limited in the amount of gain reduction by error considerations, we can then stabilize the system only by some form of derivative addition. That is, we should like to modify the GH curve favorably in the vicinity of minus one without affecting its low-frequency characteristics. Consider the locus curve in the upper right quadrant of Fig. 4. Its zero frequency intercept is nearly one and it has phase lead at higher frequencies. When combined with the GH curve, the positive real axis intercept will remain essentially at its original value, indicating no increase in steady state error. At higher frequencies, however, the GH curve is rotated away from minus one, for the positive angle of the derivative action, when added to the negative angle of the original GH curve, results in a smaller angle of phase lag.

Should we add to the prime relay components as shown in Fig. 7, the relay will have a transfer function of this form. These components are the hydraulic resistance R and the capacitance C. The resistance is a capillary tube rather than an orifice, for Poiseuille's law of flow then applies, that is, the flow is proportional to the pressure drop. This relationship may be expressed as:

$$Q=(P_1-P_2)/R \qquad (13)$$

where Q=Flow in cubic inches per second,
R=Reciprocal of Flow/Pressure, or, in units, pounds seconds/inches[5].

If we assume pressure P_2 to be changing at the rate dP_2/dt, then the bellows plate deflection will be $dP_2/dt \times$ area $\div$ spring rate, and the volumetric change dV/dt will equal $dP_2/dt \times$ area$^2 \div$ spring rate. But as dV/dt is flow rate Q, then:

$$Q=C\,dP_2/dt \qquad (14)$$

where C=Bellows area^2/spring rate, or in units, inches^5/pound.

Equating the flow which is common to the resistance and capacitance:

$$Q=(P_1-P_2)/R=C\,dP_2/dt \qquad (15)$$

or then:

$$P_2=P_1/(1+RCp)=P_1/(1+pT_4) \qquad (16)$$

where T_4 is the characteristic time or time constant RC of the network.

The equation of the primary relay will be:

$$(Ek_7+P_1A_2-P_2A_2)/k_8=z=P_1k_9$$

where E = Speed error,
k_7 = Governor force per unit speed error,
A_2 = Piston area,
k_8 = Governor spring rate,
z = Valve deflection,
k_9 = Valve deflection/developed pressure (Fig. 6)

Combining equations (16) and (17), and expressing P_1 as equivalent selected speed, n_2, the primary relay transfer function will reduce to the form:

$$n_2/E=k_7(1+pT_4)/[k_8k_9+(k_8k_9-A_1)\,pT_4] \qquad (18)$$

Now if A_1 is any positive number less than k_8k_9, this expression when plotted will have the form of the phase leading transfer function of Fig. 4. For convenience, the constants of equation (18) have been combined resulting in the general form:

$$n_2/E=(1+pT_4)/(1+\beta pT_3)\alpha \qquad (19)$$

If the reader finds it a little difficult to visualize the operation of this unit,

we might suggest an approach which the writer has frequently found helpful. Suppose that the force due to P_1 be plotted as a sine wave as shown in Fig. 8. Referring again to Fig. 7, we can

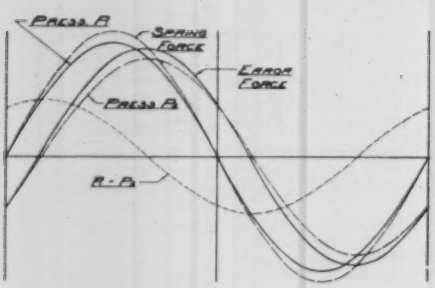


Fig. 8

realize that pressure P_2 must always follow or lag P_1 as P_1 changes. Now we can plot the force due to P_2, for we know that it has the same frequency as P_1 and, either from equation (16) or by physical reasoning we know that its slope must be zero when P_1 equals P_2. Thus its points of maximum and minimum amplitude must lie on the P_1 curve.

P_1 is equivalent to valve position and the change in spring force is due to valve motion. The spring force must then be in phase with P_1. Concerning the spring force, we know also that if the valve for instance moves up, the increase in spring force must be greater than the force increase due to P_1. Otherwise the motion would persist to the physical limit of the device and the error signal would lose control. (This is the reason for the restriction in equation (18) that A_2 must always be less than k_8k_9.) Hence we can plot the force due to the spring as shown in Fig. 8, knowing that it is in phase with and greater than the P_1 force curve.

We know also that the sum of all of the forces acting on the pilot valve must equal zero. The forces due to the spring and P_2 oppose the forces due to the governor flyweights (or error) and P_1. When the error force curve is developed, it will be found to lag the P_1 force curve, or in other words, pressure P_1 leads or anticipates the error.

Admittedly this is a back-door approach, for our input is obviously the error signal. Unfortunately, because of the nature of the device, it is impossible to proceed from this point unless we assume that which we seek to prove. What we have done is valid, however, and serves to show the phase relationships which exist in the unit. Of particular interest is of course the fact that we can see how and why the valve motion anticipates the error signal.

In many control systems, proportional, integral and derivative devices are employed together. At times even second derivative may be attempted, as well as double integration to eliminate velocity or tracking errors. Frequency response permits us to determine logically the effects of these devices when used in such combinations.

Throughout this discussion we have assumed linearity and continuity of system reactions, for the method of frequency response is valid only under such circumstances. Actually, in a great many systems linearity does not exist, and this is true of the simple system which we have analyzed. For instance, the flyweight force of the governor is proportional to the square of the speed. Such non-linearities can be effectively treated by approximating the function curve as a series of slopes and separately analyzing reactions in the range of these slopes. Experimentally, this same effect may be achieved by applying an input sinusoid of very small amplitude.

If the reader is hard pressed to understand why an analysis based upon sinusoidal signals is applicable when the general control input is usually quite random in character, it may be suggested that the Fourier Series provides the theoretical tie. Consider a possible random input is shown in Fig. 9. It, or

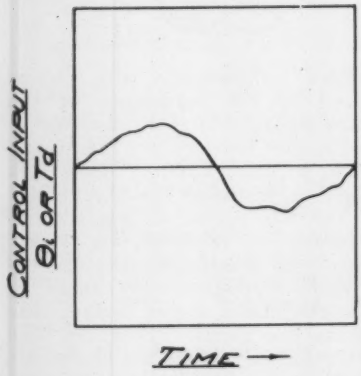


Fig. 9

even one which is both non-cyclic and non repetitive, can theoretically be resolved by the method of harmonic analysis (Fourier Series) as a sine series of various harmonics. Now as frequency response includes system reactions for the entire frequency spectrum, then any random input is automatically included.

We have also neglected the subject of friction. If the friction in the system be of the dry sticking or Coulomb type, we cannot include it in the analysis and must consider its effect by whatever *ad hoc* consideration appears justified. Viscous friction, however, can be directly expressed mathematically as a force proportional to the velocity of the member concerned and thus combined in the component equation.*

The method of frequency response is applicable to the study of considerably more complex systems than the simple single-loop system we have considered. In fact it becomes the only mathematical approach of any real value in treating such systems. It will also be evident that system parts may be independently analyzed—a feature not true of the somewhat more direct but cumbersome method of transient analysis. Further, the experimental and mathematical approaches to frequency response beautifully complement one another, the data from either approach being easily compared or combined with those of the other.

The outstanding feature of the frequency-response method is one which can only be fully appreciated when experience is gained in its use. Then one discovers that he no longer does his control thinking in the familiar, and often vague and misleading, step-by-step manner but rather in the precise terms of phase shift and gain.

*EDITOR'S NOTE.—See "Measuring the Coulomb and Viscous Components of Friction" by Charles Kennedy, *Instruments*, Vol. 15, Oct. 1942, pages 404-410. It is being recognized as almost a "classic" on this subject. —MFB.

ACKNOWLEDGEMENTS

For valuable suggestions the writer is indebted to Professor Donald Campbell of the Massachusetts Institute of Technology, J. D. Peterson of the Bendix Aviation Corp., M. F. Behar, Editor of *Instruments*, and R. Z. Hague, Chief Engineer of the National Meter Div., Rockwell Mfg. Co.

Appreciation is also due many of the writer's associates at the Cornell Aeronautical Laboratory for their assistance, particularly Messrs. Crowell, Dell'Amico and Frissel.

Nor would this acknowledgement be complete without mention of W. Ahrendt to whom the writer is indebted for his own introduction to frequency response. Mr. Ahrendt is presently collaborating with J. B. Taplan in the writing of a book on control theory, which promises to be one of the most interesting and instructive in the field.

The paper of J. D. Peterson listed in the bibliography is to be particularly recommended, for it treats the subject from the viewpoint of the design engineer and includes a carefully worked out sample analysis. The article of H. L. Hazen provides valuable introductory material on analysis procedures and terminology. [EDITOR'S NOTE. —Hazen was the first to derive and publish a system of dimensionless equations for designers and users of servomechanisms.—MFB]

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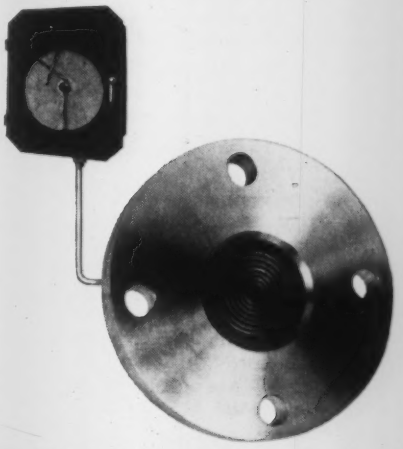

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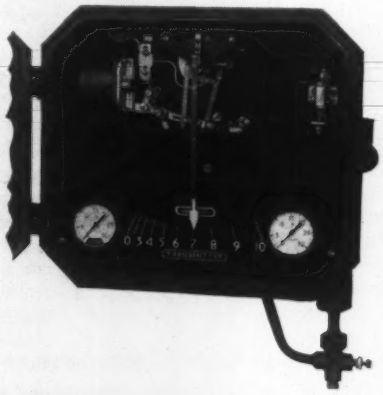

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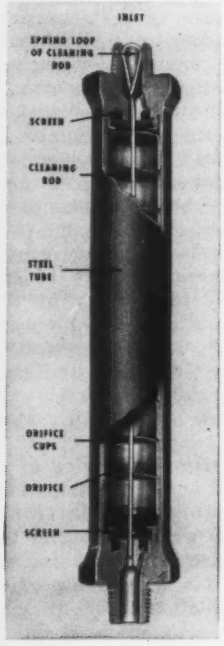

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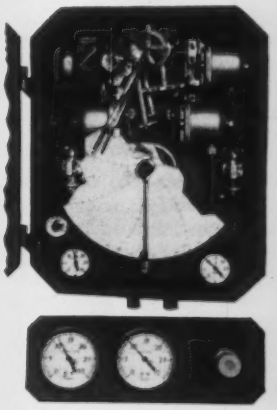

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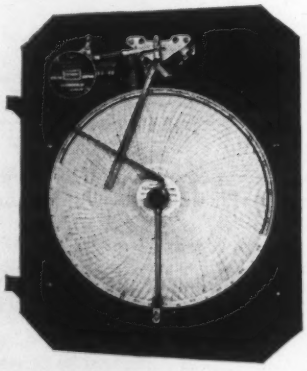

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Contact Failure Probabilities

By RONALD L. IVES, Indiana University, Bloomington, Ind.

Abstract — Elementary probability formulae can be employed to forecast the approximate over-all dependability of many types of electrical instruments and control equipment; to indicate optimum maintenance schedules; and to evaluate projected instrument modifications. Simpler applications of these methods to contacting devices are here outlined.

Introduction

THERE are few theoretical limitations upon the number and complexity of operations which can be performed by electrical and electromechanical recording, computing and control devices. Unfortunately, however, there are numerous practical limitations, so that many instruments, theoretically able to "do anything but lay eggs," not only are not built, but probably are not worth building.

Major limiting factors are the rapid increase in maintenance needs as the number of components is increased; and the lowering of over-all dependability as the system is expanded.

Maintenance needs apparently increase approximately as the square of the number of fallible components in a given system. Calibre of the maintainer required increases at approximately the same rate[1]. In consequence, cost of keeping a complicated electrical system in continuous dependable operation is often enormous.

Types of Contact Failure

Standard electrical components, of dependable manufacture, are customarily factory-tested, and their probable service life and failure rate, under a variety of operating conditions, including, in some instances, total neglect, is known. Optimum maintenance schedules, upon which many dependability ratings are based, are usually recommended by the manufacturer.

Most contact failures fall into two general classifications—*skips*, in which one or more operations are missed, following which normal operation is resumed, without external interference; and *sticks*, in which, once an operation is missed, attention is needed before normal operation is resumed.

Because *sticks* are not only easily detectable, but are usually preventable by minor changes in mechanical or electrical design (such as dust covers and spark absorbers), they are seldom encountered in properly maintained modern communication equipment. In many instances, the average number of operations per *stick* exceeds the rated maintenance interval of the component.

Skips, on the other hand, are not only hard to detect by any simple means, but are virtually impossible to eliminate by any known design improvements, although their frequency can be markedly reduced, in most instances, by careful attention to design and maintenance. Many *skips* are caused by extraneous factors, such as building vibration, condensation of moisture, or vagrant dust motes. Together, these factors are sometimes referred to as the "poltergeist effect," or, more recently, as "gremlins."

Basic Formulae

Application of the general principles of probability to the problems encountered in communication engineering began more than half a century ago; and most of the basic problems of component failure in automatic switching mechanisms[2] were solved more than 20 years ago. Salient features of this work have been summarized by Fry[3]. Application of these same principles to the problems of quality control, which enables manufacturers to specify the probable dependability of their products, is outlined by Simon[4]. Fundamental theory of probability is described by Jeffreys[5]; and many applications useful in research and development work have been described by Brunt[6].

In a recording device of any kind, each input impulse either does or does not produce an impulse (or record of some sort) at the output. When an output impulse is desired for each input impulse, the failure rate of the device can be stated as

$$Rf = \frac{F}{F+S}$$

in which:

Rf = Failure rate (a ratio);
F = number of failures (input impulses minus output impulses);
S = number of successes (number of output impulses);
$F+S$ = total number of input impulses.

Likewise, the success rate, Rs, can be stated as

$$Rs = \frac{S}{F+S}$$

provided, in each case, that all impulses are classed as either successes or failures.

The examples to be presented deal with *skips*, but simple and obvious minor modifications of the reasoning make possible use of the same general formulae to determine the probable "length of run" between *sticks*, if that figure is made desirable by the nature of the components used.

Cascaded Components

In many recording and computing devices, electrical components are cascaded, so that device A operates device B, which in turn operates device C, etc. If any component, including the input device (usually an instrument), fails to operate, the entire system fails to operate, and a loss of record occurs.

With this arrangement, the success of the rate system as a whole is desired. Probable success rate is shown by

$$Rs = \left(\frac{S_1}{F_1+S_1}\right)\left(\frac{S_2}{F_2+S_2}\right)\left(\frac{S_3}{F_3+S_3}\right)\cdots\left(\frac{S_n}{F_n+S_n}\right)$$

there being n components in the system, each having its own rate of success. If all components are alike in their success rate, the formula becomes

$$Rs = \left(\frac{S_1}{F_1+S_1}\right)^n$$

Parallelled Components

When two or more components are connected in parallel, so that all receive the same input impulses, and if any one of the group operates, a corresponding output impulse is produced, the skip rate of the group is markedly reduced[7]. Known the probability of failure of a single component, that of a paralleled group is

$$Rf = \left(\frac{F_1}{F_1+S_1}\right)\left(\frac{F_2}{F_2+S_2}\right)\left(\frac{F_3}{F_3+S_3}\right)\cdots\left(\frac{F_n}{F_n+S_n}\right),$$

there being n components in the group. The success rate is shown by the formula

$$Rs = 1 - Rf$$

If all components have like characteristics, as is usually the case, the success rate is given by

(1) Because maintenance salaries seldom increase in proportion to the difficulty of the work, many competent maintainers enter the comparatively more lucrative field of engineering, producing a chronic and long-standing scarcity of top-rank maintainers.

(2) Component failure, in many instances, is actually failure to give the desired service, rather than "something didn't function."

(3) T. C. Fry, *Probability and its Engineering Uses*, New York, 1928.

(4) L. E. Simon, *An Engineers' Manual of Statistical Methods*, New York, 1941.

(5) Harold Jeffreys, *Theory of Probability*, Oxford, 1939.

(6) David Brunt, *The Combination of Observations*, Cambridge, 1931.

(7) According to current shop superstition, if a number of components are paralelled, the skip rate of the group equals the skip rate of a single component multiplied by $1/n2$. Although this is mathematically incorrect, the error is on the "safe side," sometimes by several orders of magnitude.

$$Rs = 1 - \left(\frac{F_1}{F_1 + S_1}\right)^n$$

Hence, parallelling of components increases the success rate of the group appreciably, if the components are truly parallelled. Because a parallelled group will continue to operate, after a fashion, so long as any component is operating; parallelling, instead of reducing the failure rate of a system, may be a source of undetected error if, unknown to the operator, a part of a parallelled group is out of service.

Branching Systems

When two or more branch systems supply impulses to a main system, the probable success rate of the entire assembly is the sum of the success rates of the infeeding branches multiplied by the success rates of the main system, provided there are conflicts of functions, or overlappings of impulses supplied to the main system.

The problems of circuit conflicts and overlappings of impulses are substantially those of traffic congestion and double connection in a telephone system, and have been discussed competently by Fry.[8]

Most recording instruments, even the more involved self-computing types, are relatively simple, so that overlaps and conflicts can be eliminated by design improvements, reduced by use of interlocking circuits, or made statistically constant by use of time lag equipment. Use of interlocks and similar protective devices is instrumentally desirable, however, only when the device eliminates more trouble than it causes; and may, even under such conditions, be economically undesirable because of increased material and maintenance costs.

When a main system feeds two or more branches, the success rate at the end of each branch is the success of th main system, multiplied by that of the branch under consideration. With this arrangement, failure of the main system will cause simultaneous failure of *both* branches.

Maintenance Schedules

With electrical components of many types, dependability, or success rate, is a function, often complex, of the time lapse (or number of operations) since the last maintenance. For this reason, many manufacturers are quite specific in regard to the frequency of overhauls needed with their equipment.

A simplified formula for the depreciation of the success rate of an electrical component, such as a relay, as maintenance interval varies with respect to recommended maintenance interval, varies with respect to recommended maintenance interval, might be:

$$Rs = \left(\frac{S}{F + S}\right)^{t/v}$$

in which:
Rs = success rate of component;
S = number of successful operations;
F = number of unsuccessful operations;
t = actual time between maintenances;
v = recommended time between maintenances.
(number of operations may be substituted for time in both t and v above, if desired)

General formula for the success rate of a cascaded system, with the recommended maintenance intervals of the components known, for any maintenance schedule, is:

$$Rs = \left(\frac{S_1}{F_1 + S_1}\right)^{t/a}\left(\frac{S_2}{F_2 + S_2}\right)^{t/b}\left(\frac{S_3}{F_3 + S_3}\right)^{t/c}\cdots\left(\frac{S_n}{F_n + S_n}\right)^{t/m}$$

in which the subscript numerals 1, 2, 3 . . . n refer to components of the system, having recommended maintenance intervals of a, b, c . . . m respectively. From this formula, the success rate of the system for any given maintenance interval, including "total neglect," may be computed; or the maintenance interval necessary for any (attainable) success rate can be found. Depreciation of the success rate of a component does not always follow as simple a formula as the sample given above.

Practical Example

To illustrate part of the foregoing with simple examples, let us consider a cascaded system with 20 compononts, all having the same characteristics. The general formula for its success rate is:—

$$Rs = \left(\frac{S}{R + S}\right)^{20}$$

If the success rate of a single component is 0.99, which is typical of a cheap "radio" relay (59 cents each), the success rate of the system is 0.99^{20}, or 0.8179. If, however, the success rate of a single component is 0.9999, which is characteristic of a medium-grade telephone relay, the success rate of the system will probably be 0.9999^{20}, or 0.99802. In the first instance, the system will probably fail more than one-sixth of the time; in the second, it will probably fail less than one five-hundredth of the time.

If, in the first instance, each component is replaced by a pair of identical components in parallel, the success rate of each pair (in parallel, and performing a single function) is probably $1 - (0.01)^2$ or 0.9999. The system, with this arrangement (containing 40 components but performing only 20 functions) has the same probable rate of success as if the better components of the second example above were used (but with better components, only 20 are needed to perform 20 functions)!

If it is assumed that the cascade of poorer components above has a probable success rate of 0.8179 when maintained each 10,000 operations, the effect on the success rate of variations in the maintenance interval is shown by:—

$$Rs = (0.8179)^{t/10,000}$$

Neglect of maintenance for five periods will cause the probable success rate of the system to degenerate to 0.8179^5, or 0.3660; but if the system is maintained every 2,000 operations, the probable rate of success becomes $0.8179^{1/5}$, or 0.9606.

Changes in the maintenance interval of the system containing better components will follow the same formula (using 0.99802 in place of 0.8179), but the success rate of this system is much less sensitive to changes in the maintenance schedule than is that of the system containing poorer components!

Summary and Conclusions

Application of the simples phases of the laws of probability to the problems of instrument design, modification AND MAINTENANCE will, in many instances, eliminate a considerable part of the "error" from the "trial-and-error" which is an integral part of all experimentation.

Such computations will indicate, in advance of construction, the probable effect on the over-all dependability of a system of the introduction, modification or elimination of a given component; and will indicate the probable effect of a change in the maintenance schedule.

In some instances, probability computations will indicate the quality of the components necessary in a projected instrument, and, as a result, will permit a more successful advance estimate of the probable cost of a commercial model.

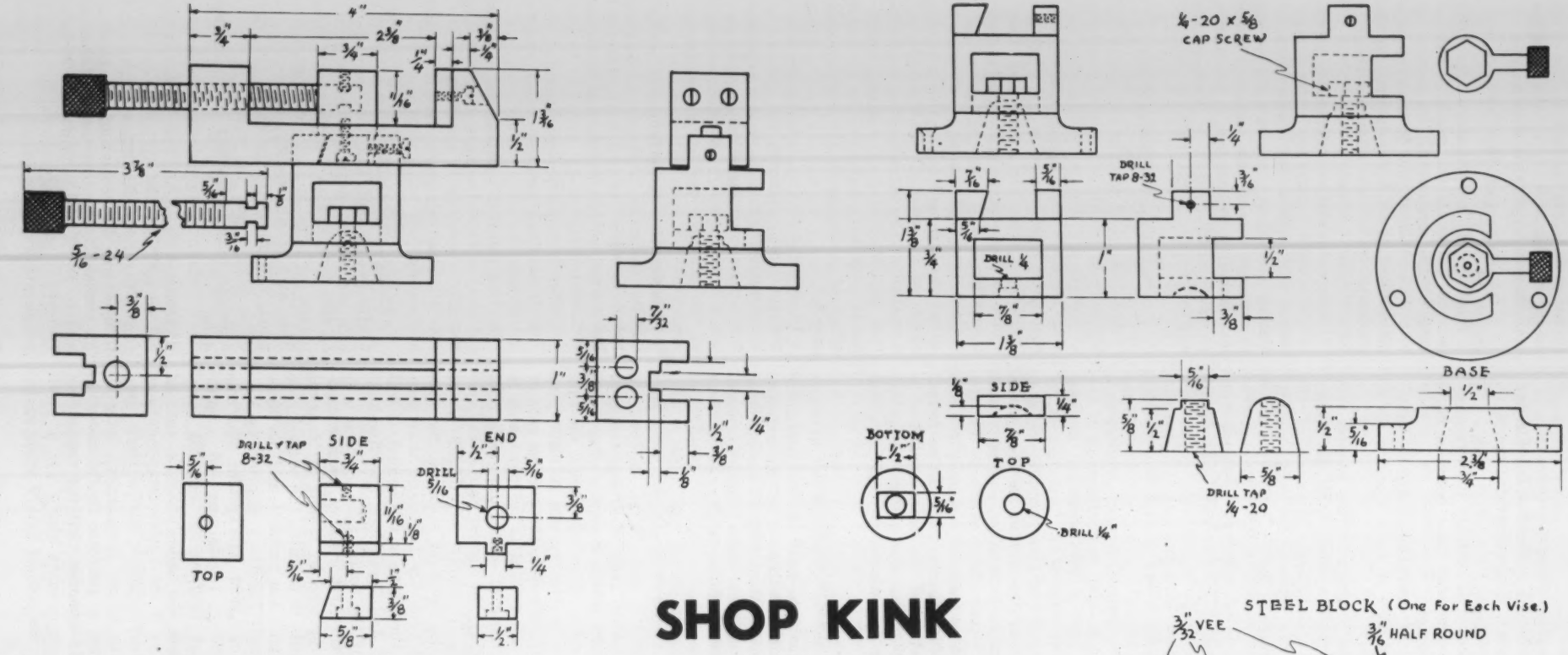
Consideration of performance probabilities indicates that the following rules, in strict accord with practical knowledge, should be followed in all instrument designs:—

1. Use high-quality components.
2. Use as few components as possible in cascade.
3. Use parallel components in critical locations (and be sure that they are actually operating in parallel).
4. Maintain equipment frequently and adequately.

Although probability is an extremely useful design tool, the final verdict on any instrument design must be based on test data, not on the designer's blueprints or preliminary computations. The laws of probability, correctly applied, will show the probable behavior of a device, but the actual performance can only be learned from the test data.

Acknowledgments. The writer is indebted to Dr. S. W. Grinnell, of Stanford University, for many helpful and informative discussions of the relation of probability to instrument failures; and to Dr. K. P. Williams, of Indiana University, for suggestions during the preparation of this article.

(8) T. C. Fry, *Probability and its Engineering Uses*, New York, 1928, pages 321-388.



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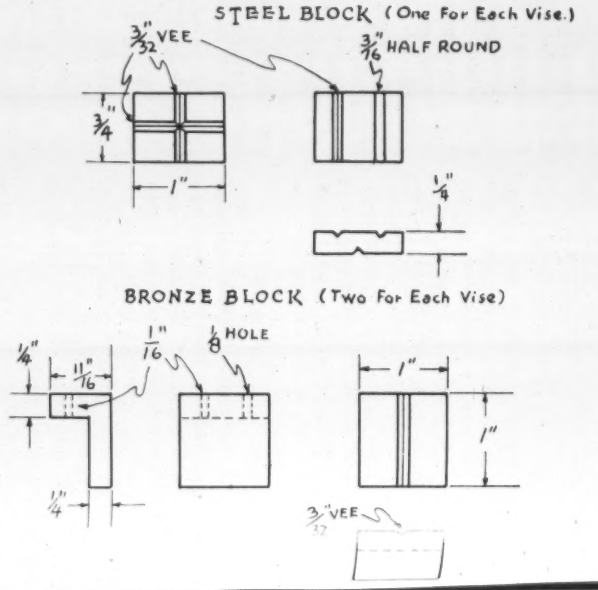
SHOP KINK

Instrument Mechanic's Fully-adjustable Vise

By RALPH BLANKENSHIP, Public Service Co., of Indiana, New Castle, Ind.

FOR several years, as electrical instrument repairman, I had been in need of a small vise, so designed and dimensioned as to enable me to hold small parts without damage to them; one that I could turn in any position. So I have made the one here drawn in detail. It does the job in good shape. The swivel base is very handy. The extra blocks made of bronze make it very useful in the repair of different instruments, also in jeweler's work. It is simple to make and the cost of materials is very low.



SHOP KINKS

Salvaging Mercury

By M. P. BRUNIG, Agricultural Engineering Dep't, College of Agriculture, Lincoln, Neb.

COLLECTION of spilled mercury, often necessary in a laboratory, is particularly difficult on rough floors. If the laboratory or shop has a good vacuum system, recovery of the mercury may be simplified by use of a flask or bottle

as a trap and a small jet as a "pick-up." The tubing from the vacuum source is attached by glass or metal tube so as to extend just through the stopper of the flask or bottle. The other tube extends from nearer the bottom of the flask to the "pick-up" jet.

This jet will easily and quickly pick up mercury from rough surfaces or from cracks between boards. The mercury is trapped in the flask or bottle, ready to be cleaned and used again. Time is saved by first sweeping scattered mercury into a smaller area for quicker pick-up.

Improvised Remote-indicating System for Valve Position

By PHILIP DEWEY, Chicago, Illinois

INSTRUMENT men are occasionally called upon to provide a remote position transmitter. There is often a need for such equipment on short notice, without the delay involved in ordering and waiting for new equipment to arrive.

The writer was recently confronted with the problem of transmitting to a control panel the position of two slide valves in a laboratory pilot plant. These valves, because of the nature of the material they are controlling, have a tendency to stick or become blocked at times. The control instrument might show the valve closed but actually it might not be. Hence the need of an indicating device to tell at a glance the actual position of the valve.

In the equipment on hand were two new Foxboro valve-positioners and the possibility of using these as pneumatic transmitters was studied. It was found that a minor change would make them suitable. In this particular positioner, the bellows is removed and reinstalled in the reverse position. The same net result could also be obtained by installing a reverse-acting air-relay. At any rate, the bellows now assumes the role of a follow-up bellows. The positioner is mounted on the valve in the usual manner, connecting the lever to the valve stem with the parts provided. The air connections are different, however. The 17-lb. air supply is piped to the regular connection. The output, which ordinarily goes to the diaphragm, is now connected to the "follow-up" bellows, placing a tee in the connection. The remaining port of the tee is then connected to the pneumatic transmission line to the control panel. The indicating device is simply a 0 to 15-lb. pressure gage, with an improvised scale to fit the particular need.

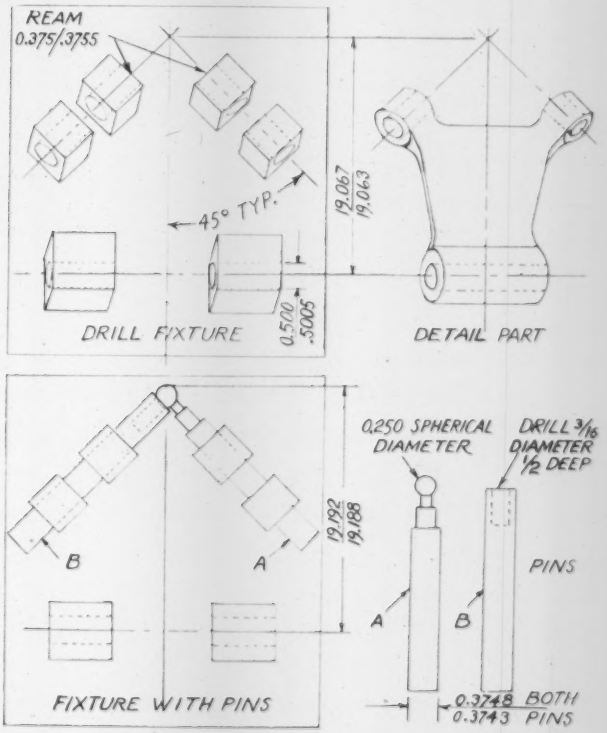
The usual procedure in adjusting is followed, using the flapper adjustment for one extreme position and the stroke adjustment to obtain the other. In cases where an exceptionally long stroke is involved, it may be necessary to set flapper adjustment fo rone extreme position and the stroke instead of at the beginning as is customary.

This set-up could be used to transmit the position of small gas holders, floats, and other devices. In cases where the capacity of the transmission line is small, pulsation may be encountered. This can be remedied by simply placing a capacity in the transmission line. An 18" section of 2" pipe will serve the purpose.

Establishing a Working Point

By MARTIN RHOADS, Baltimore, Md.

WHEN the center lines of two holes must lie in the same plane and must intersect at a point at a given distance from another hole, as is the case in the drill fix-



ture illustrated, and the detail part drilled from the fixture, the point is difficult to establish in order to make a positive check.

By making the two simple pins "A" and "B" and inserting them in the drill fixture as shown, this point is easily established; namely, the center of the 0.250" ball.

The detail part can be checked in a similar manner.

Verifying "Open" Coils

By WILLIAM J. BUDD, Jersey City, N. J.

IN production testing of coils there is always a percentage reaching final assembly that must be rejected as apparently being "open." As the coil must be replaced whether the reason is an actual break in the winding or a poor solder connection from the winding to the terminal, one

Shop Kinks *continued on page 832*

Scientific Glass Blowing and Laboratory Techniques

By WILLIAM E. BARR, and VICTOR J. ANHORN, Gulf Research & Development Company

XIV. SWIETOSLAWSKI EBULLIOMETERS

A. Design

[This section was written in collaboration with Dr. John R. Anderson, Mellon Institute of Industrial Research*]

Any kind of apparatus designed for carrying out determinations of the boiling points of liquid substances or solutions may be called an ebulliometer. This term, however, is usually associated with the precision devices invented by the Polish scientist, W. Swietoslawski.[1] By using this equipment, in conjunction with adequate thermometric instruments, the boiling temperature of liquids and solutions, and the condensation temperature of vapors, may be measured with a precision of $\pm 0.001°C$.

Precise ebulliometric measurements require not only specialized apparatus, the construction of which is presented here, but also specialized techniques based on the principle of comparative measurements; the techniques have been described in an authoritative monograph[1] which should be perused by all investigators prior to application of the ebulliometric method.

In addition to their use for precise determinations of boiling points and condensation temperatures, ebulliometers may be employed for determination of the ebulliometric degree-of-purity of liquid substances and azeotropes; calibration of thermometers; measurement of changes in pressure; determination of the impurity content and moisture content of liquid and solid substances; study of azeotropy; determination of the amount of vapors adsorbed by solid substances; examination of thermal resistivity of liquids and solids; molecular weight determinations; examination of physicochemical standards, and the determination of solubility and equilibrium constants.

In general, in order to use the ebulliometric method in these varied applications, different types of ebulliometers are required.

Standard Ebulliometric Elements

In 1942 J. R. Anderson, in consultation with Professor Swietoslawski, undertook the design of a set of standard ebulliometric elements provided with standard ground joints, from which almost any kind of ebulliometer might be arranged. Use of these standard elements, shown in Fig. 175, has simplified the construction of ebulliometers to such an extent that they are now replacing the previous designs. For this reason most of this article is devoted to a description of them.

Element A (Fig. 175) constitutes the boiling-temperature section of all ebulliometers in which boiling temperatures are to be measured. It consists essentially of a spherical reservoir (which is partly filled with the liquid under examination), a cylindrical activated boiler, a thermometer well, and a drop counter. The theory of its functioning has been elaborated on elsewhere.[1] B. is a condensation temperature element which may be used in all ebulliometers in which one or more condensation temperatures are to be measured. C is a rectifying column without packing, for use in differential or multistage ebulliometers in which only moderate rectification of vapors is desired. Element C may also be used, like element D, as an ordinary condenser. Elements D and E form, together, a special condenser system so designed that moisture may be removed from the substance under examination by distillation of a very small amount of material. E is also equipped with a ground joint for holding element H (a receiver for collection of small amounts of distillates containing moisture), and with a side-arm for connecting the assembled ebulliometer to a "manifold" (to which other ebulliometers each operated under the same inert atmosphere and under the same pressure, may be adjoined). It is sometimes convenient to seal the side-arm of element E to the manifold through a 3-way stopcock of large bore; in this way one may isolate any one ebulliometer from the others. Alternatively, the side-arm may be connected directly to a drying-tube.

Element F is a conventionally-packed fractionating column with a side-arm sealed, just below the heated section, to the central tube. Element G is an ordinary round-bottomed flask,

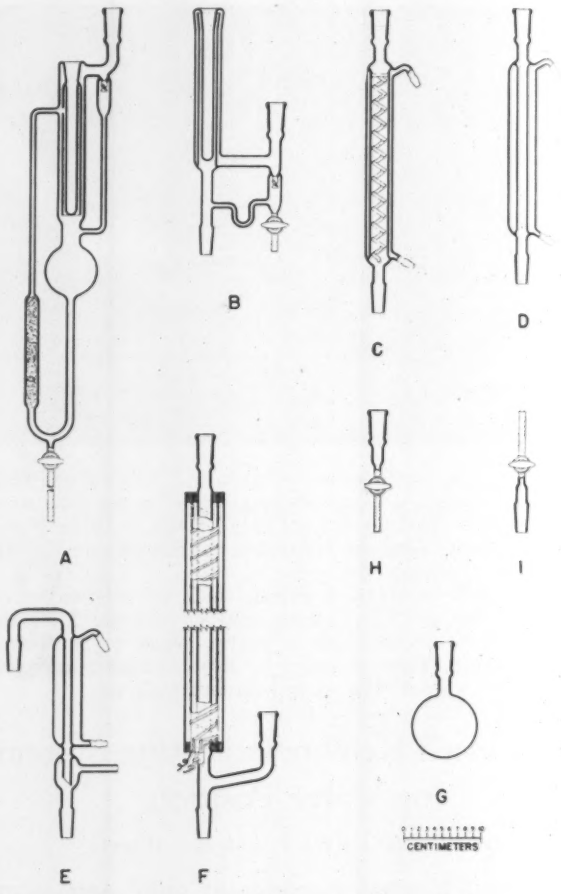


Fig. 175

and I is an inner ground joint to which has been sealed an ordinary stopcock. The usefulness of the latter element will be apparent later.

It has previously been emphasized that ebulliometers constructed with ground joints cannot be used for tonometric measurements.[1] In addition, it has now been found by experience that it is rather difficult to assemble firmly, from the standard elements, complicated ebulliometers—especially after the elements have been properly insulated. Difficulties also arise in removing moisture, as a heteroazeotrope, from an ebulliometer constructed with ground joints. Heteroazeotropes condense in the joints, for the latter must not be lubricated, and the water may leak back into the vapors of the substance under examination (even after several hours of operation). To heat the joints with a gas flame[1] is not always an adequate solution, particularly if the joints themselves must be well insulated.

For these reasons, it is recommended that, for very precise work, the use of ground joints other than the one for holding the receiver, shown on element E (Fig. 175), should be

*Acknowledgement is gratefully made to Professor W. Swietoslawski for suggestions made during the writing of this section.

[1] W. Swietoslawski, "Ebulliometric Measurements," Reinhold Publishing Corp., New York, 1945.

abandoned. Standard elements *without* ground joints should, however, be retained during construction, shipment, and assembly of the apparatus. Almost any kind of ebulliometer may be constructed by sealing the various elements together in the laboratory in which the apparatus is to be used. Ebulliometers of one kind may then be transformed into those of another simply by removing certain elements and resealing them in another position. In all cases, the only seals required for this purpose are of tubing of 16 mm. diameter. It should be emphasized, however, that in some laboratories standard elements with ground joints are used successfully.

Beckman-thermometer Wells

The thermometer-wells in elements A and B (Fig. 175) have been designed to accommodate long-stemmed Beckman thermometers. The disadvantages of thermometers of this type have been enumerated[1] and, as has also been pointed out[1], if improved Beckman thermometers should become available in the future in the United States, the wells in elements A and B may then be shortened. Most of the difficulties encountered in using Beckman thermometers are associated with improper design of the tube connecting the mercury bulb with the capillary which covers the scale of the thermometer. If, however, ebulliometers are adapted to this thermometer, and if the experimenter avails himself of an appropriately-chosen method of comparative measurements, accurate results are obtainable. In the United States there has been a tendency to discard the Beckman thermometer in favor of the more costly platinum-resistance instrument. The correct solution, however, is to plan the experiment well (by basing it on the comparative principle). One may then obtain excellent results without using expensive temperature-measuring equipment.

In order that element B may function properly, vapors must first pass upwards *around* the thermometer-well and then downwards to the side-arm leading to other parts of the apparatus. If the hydrostatic pressure of the liquid in the U-tube of this element does not exceed the "vapor head" established around the thermometer-well, or if, at the start of the experiment, *total* condensation takes place around the thermometer-well, vapors may pass through the U-tube. So as to circumvent this difficulty where it arises, i.e. if high boiling liquids are being examined, the U-tube should be made somewhat deeper, especially when element B is connected directly with condenser element D as in Fig. 179. An artifice often convenient for overcoming this difficulty consists in heating the condensation element with an auxiliary heater which will be described in detail later. Of course, elongation of the U-tube of element B influences unfavorably the liquid "hold-up" of the apparatus.

Just enough mercury to cover the bulb of each Beckman thermometer is placed in the respective wells before the ebulliometers are put in action, and the mercury is then covered with a thin layer of mineral oil. It has been pointed out that it is necessary to keep the hydrostatic pressure (exerted by the mercury[1]) constant in the various wells into which the thermometers are successively transferred. It has also been emphasized that the presence of mercury in the wells creates a constant danger that the experimenter might be poisoned by mercury vapors.[1] In addition, it is important to keep the thermometer reasonably well centered in the mercury in order to avoid direct contact between the bulb and the well walls.

These three problems are not unrelated, yet no adequate simultaneous solution to all of them has previously been given. The solution is actually quite simple. First, a group of well-matched thermometers should be selected. Their bulbs should be as uniform as possible as to diameter and to length. In addition, the diameter of the tube containing the long "capillary" connecting the thermometer bulb and scale capillary should be the same for all thermometers chosen, and the position of the seal between this "housing" and the scale "housing" should in each thermometer be the same distance away from the bulb. These conditions are not difficult of fulfilment if the thermometers have all been manufactured by the same firm, but thermometers from different firms are likely to be far from uniform. Secondly, until

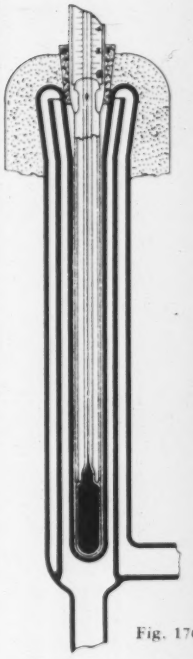


Fig. 176

Fig. 177

standard specifications have been established for Beckman thermometers, the ebulliometers should be constructed to suit one of the matched instruments. The height and diameter of the thermometer-wells, and their shape in their upper section, should be such that a small portion of the scale "housing" will be surrounded by the insulation which covers the thermometer-well (see Fig. 176). A tight-fitting relatively long rubber stopper should be placed around the thermometers at such a position that, with the well uninsulated, part of the stopper fits snugly in the top of the well. Insulation, to be described in detail later, is now applied at the top of the well so that it fits around the upper part of the stopper. Two pieces of relatively wide Nichrome ribbon, or other suitable conductor not corrodable by mercury, should be placed under the stopper and on opposite sides of the thermometer from about one inch above the stopper down to the top of the bulb. These ribbons, which are not shown in Fig. 176, may be held in close contact with the thermometer with cellulose tape or threads. An amount of mercury just sufficient to make contact with the lower ends of the ribbons (when the thermometer is in place) should now be put in each well. A "test for contact" consists in using the mercury in the well as a switch which will turn on a tiny light-bulb when both ribbons touch the mercury. A convenient device for completing the circuit is shown in Fig. 177. It consists of a small "dry" cell with a very small light-bulb soldered onto the positive pole, and a pair of leads, one from the other bulb terminal and one from the shell of the "dry" cell. When adjusting the position of the thermometer, the leads from this device are put into contact with the upper ends of the ribbons; the thermometer is in the correct position when vertical movement of the thermometer through about one millimeter will just make or break the electric circuit, as evidenced by the light.

Ebulliometers from Standard Elements

Elements A, D, and E (without connecting ground joints) may be combined as shown in Fig. 178 to form a simple ebulliometer. A differential ebulliometer for molecular weight determinations, constructed from elements A, B, D, and E is shown in Fig. 179. Elements A, C, B, D, and E have been arranged, as shown in Fig. 180, to form a differential ebulliometer for determination of the ebulliometric degree-of-purity of liquid substances or of homoazeotropes. Element H may be used in conjunction with these apparatuses when one desires to remove a small amount of distillate containing moisture.

If the problem of the experimenter is simply that of measuring boiling temperatures of liquids or solutions, and if he

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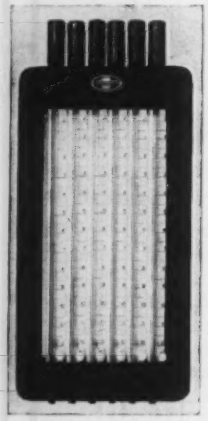

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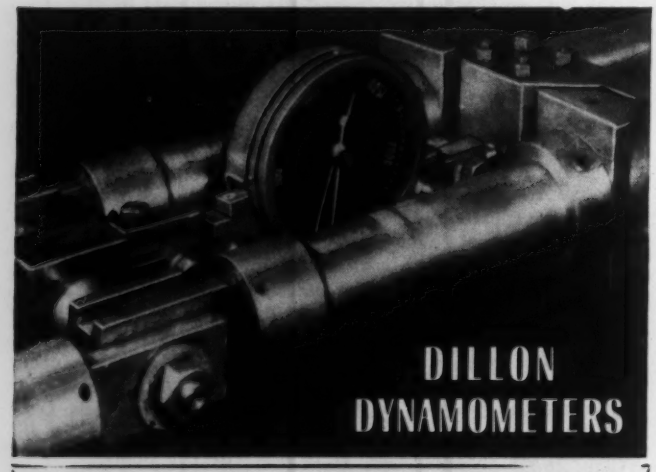

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WRITE FOR LITERATURE

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has at his disposal equipment for making, with the desired accuracy, absolute temperature and pressure measurements, a simple ebulliometer (Fig. 178) is all that is required. On the other hand, should it be desired to carry out comparative ebulliometric measurements, two ebulliometers, one of which is differential (Fig. 179 or 180) should be employed.

For simultaneous measurements of boiling and condensation temperatures without appreciable rectification of the vapors (as in molecular-weight studies) a differential ebulliometer of the type shown in Fig. 179 is all that is required. If, however, such measurements are to be based on a strictly comparative method, a simple ebulliometer for correcting the boiling and condensation temperatures, before and after the introduction of the solute, should also be employed. It is very rare for an organic solute to be completely non-volatile in the solvents ordinarily used. Indeed, the combined use of simple and differential ebulliometer allows the experimenter to obtain some idea as to the extent of this volatility and, further, allows him to choose as his standard a solute which has the same, or practically the same, relative volatility. If a very small amount of the solvent, from which the solute was originally crystallized, or some moisture contaminates the solute, their presence may be detected if two ebulliometers are employed. Some solvents (e.g., benzene) very often used in molecular-weight studies are difficult to keep anhydrous during handling, and in addition their condensation temperatures are highly sensitive to moisture content. When used in conjunction with a simple ebulliometer, the ebulliometer shown in Fig. 179 offers the possibility of detecting the slightest changes in moisture content of different portions of the same preparation of solvent. Furthermore, a relatively large volume of solvent is used in the differential ebulliometer, and, if necessary, an accurately-measured amount (containing practically all the moisture) can be removed *before* the solute is added. With benzene, or any other liquid forming heteroazeotropes with water, practically all the water can be removed by distilling off two or three milliliters. These advantages are not the least among those obtainable when ebulliometers of this type are used for molecular-weight work. It should be emphasized, however, that a less strict method of comparative measurements can be applied in molecular-weight work should only one ebulliometer—a differential one (Fig. 179)—be at hand.[1] Then, to

Fig. 178

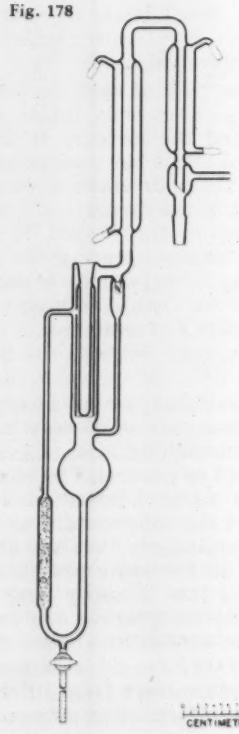
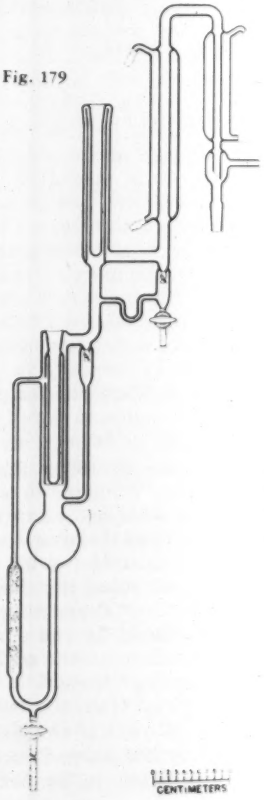


Fig. 179



molecular-weight determinations based on the comparative principle can be made with two *simple* ebulliometers.[1]

Where ebulliometers are constructed for those molecular-weight investigations which involve direct addition of solute to the solvent in the ebulliometer, it is necessary to seal onto the spherical reservoir of element A a side-arm with a ground glass stopper (similar to that adjoined to the pear-shaped reservoir as shown in Fig. 188).

For determining the ebulliometric degree-of-purity of a liquid substance or a homoazeotrope, a differential ebulliometer with a rectifying element C (Fig. 180), and a simple ebulliometer (Fig. 178) are required. For determining the ebulliometric degree-of-purity of heteroazeotropes, special devices which *cannot* be built from the standard elements here described have been recommended by Swietoslawski.

Fig. 181 shows an ebulliometer in which condensation temperatures, only, can be measured—one, *before;* and one, *after,* rectification of the vapors; it has been recommended[1] for examination of the purity of high-boiling liquids. The sensitivity of this device may be improved upon by replacing element C with a packed column (element F) as shown in Fig. 182. The lower part of this column should be equipped (as shown in Fig. 175 and 182) with a side-arm for holding an additional element E which is provided with a stopcock (element I). Measurements for this purpose in this device are made not simultaneously but alternately—first, before rectification and second after the vapors are passing through the column. Appropriate manipulation of the stopcock of element I, and of the coolant in the lower element E, makes these measurements possible.

Determinations of the degree-of-purity of liquid substances or homoazeotropes usually follow experiments in which relatively large amounts of the substance under ebulliometric

Fig. 180

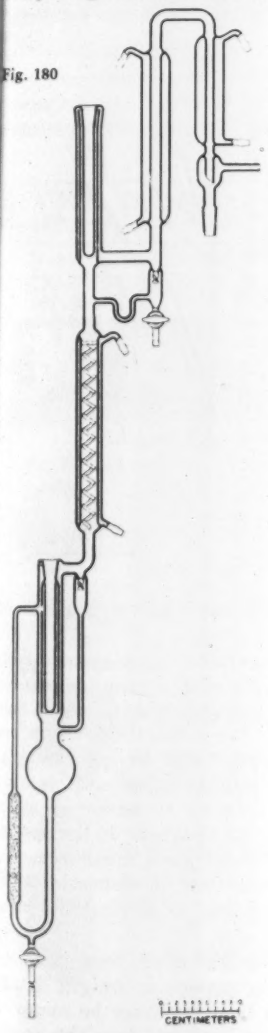
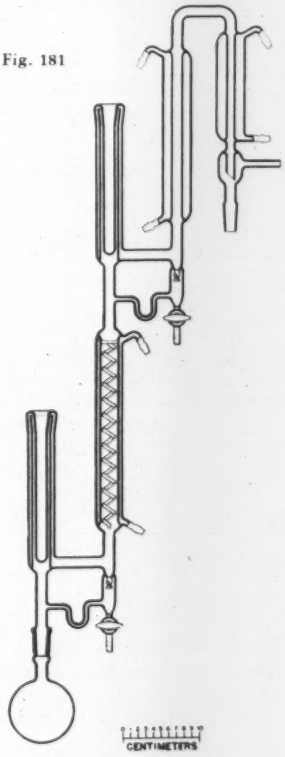


Fig. 181



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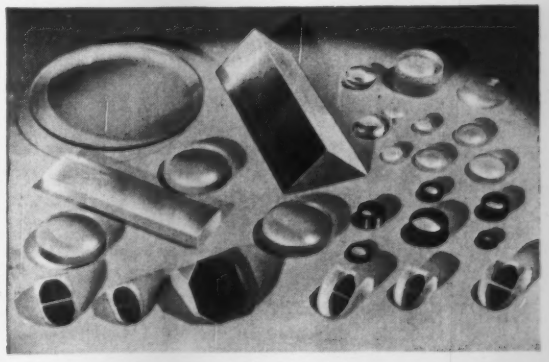

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Fig. 182

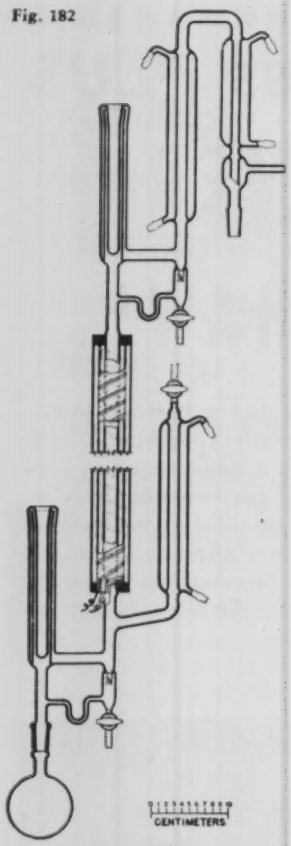


Fig. 183

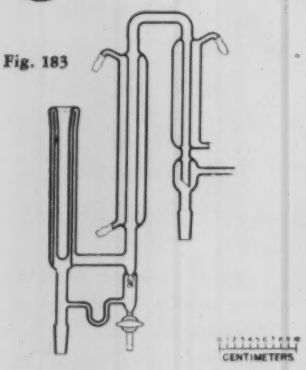


Fig. 184

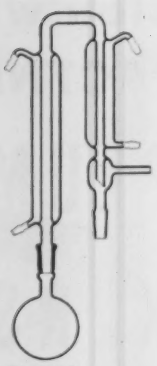


Fig. 185

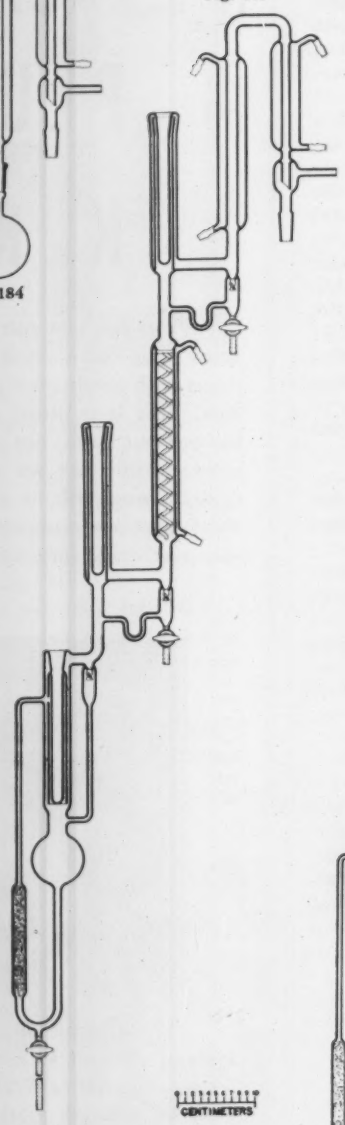


Fig. 186

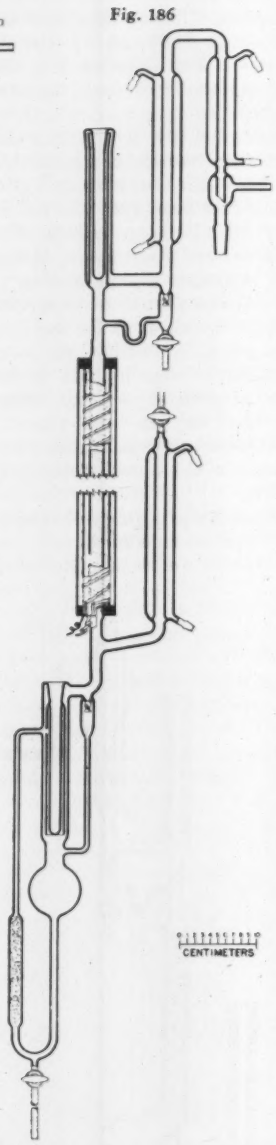
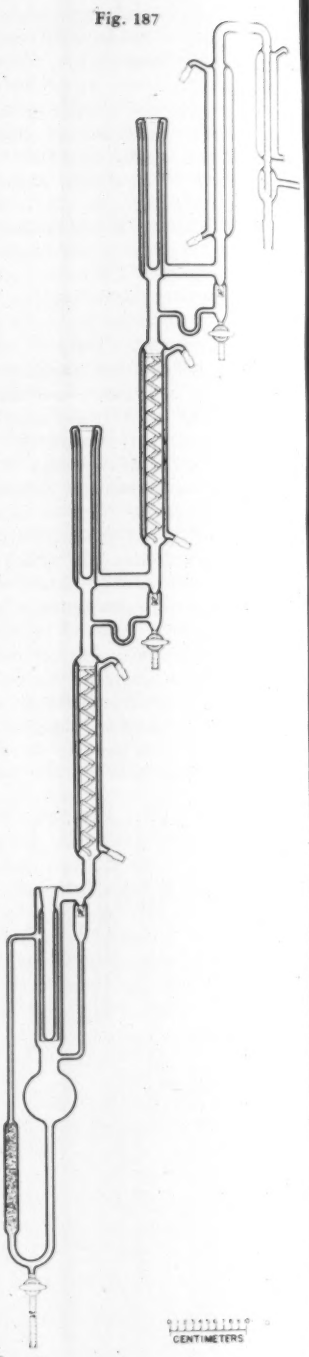


Fig. 187



examination have been rectified in efficient columns. This is a consequence of the fact that, very often, so-called "heart cuts" from a distillation are not necessarily the purest samples from the cryometric or the ebulliometric point of view. In such work, a great deal of information regarding the nature of the impurities present can be obtained if the experimenter has a precise condensation-temperature curve for a large sample, as well as precise ebulliometric and cryometric degree-of-purity data on the various fractions. For precise measurements of condensation temperatures at the head of a distilling column, the device shown in Fig. 183, constructed from elements B, D and E, is to be recommended. The change in condensation temperature as a function of volume of distillate can be obtained to an accuracy of one or two thousandths of a degree when using this head in conjunction with a simple ebulliometer which contains a relatively pure sample of the substance under examination. Thus, for examination of the purity of substances by the ebulliometric method, a distilling column provided with the head shown in Fig. 183, a simple ebulliometer, and a differential ebulliometer for determining the ebulliometric degree-of-purity of the fractions are required. Usually, all of these devices should be connected to a common manostat so that, if desired, the operations can be carried out at a predetermined pressure and under an inert atmosphere. The same equipment is also to be recommended for use in studies of homoazeotropy.

The device shown in Fig. 183 has other important applications; for example, when equipped with a round-bottomed flask (element G) containing a reference substance, it can be used like a simple ebulliometer for correcting (for pressure fluctuations) the temperature found in an identical device acting as the head of a distilling column. It is also useful for drying certain liquids (such as benzene) azeotropically if it is desired to follow the progress of the operation by temperature measurements. If such measurements are not desired, an apparatus consisting of elements D, E and G, as shown in Fig. 184, suffices for drying the substances.

Fig. 185 shows a differential ebulliometer (composed of elements A, B, C, B, D and E) for molecular-weight determinations in which it is necessary that moisture be removed from the solute *after* the latter has been put into the appa-

ratus. Swietoslawski has cited the interesting work of Centnerszwer and Lazniewski on the use of apparatus of this type where salts, which were practically impossible to dehydrate except by heteroazeotropic distillation, were the objects of the investigation.

Fig. 186 shows an especially sensitive differential ebulliometer used for determining the degree of purity of ultrapure liquids or homoazeotropes, or for microanalytical determinations of impurity-content.[1] Fig. 186 differs in principle from the ebulliometer shown in Fig. 180 only in that provision has been made for more efficient rectification of vapors. It is operated in a manner similar to that recommended for the ebulliometer shown in Fig. 182 (in order to eliminate corrections for the fall in pressure across the column packing).

Finally, a multistage ebulliometer for measurement of boiling temperature and condensation temperatures after varying degrees of rectification, is shown in Fig. 187. The rectifying elements in Fig. 187 may, with other suitable changes, be replaced by standard elements F. Such devices permit determination of the distribution, with regard to condensation temperature, of components of a liquid mixture.

Special ebulliometers, of use for examining amounts of substances smaller than would be mandatory if the standard element A were employed may be constructed by making smaller the spherical reservoir, and reducing the size of the activated cylindrical boiler of that element.

Unfortunately, there are two kinds of ebulliometers which *cannot* be constructed from the standard elements: (*a*) ebulliometers for measuring the boiling and condensation temperatures of two immiscible liquids, and (b) ebulliometers for examining liquids containing small amounts of highly volatile components.[1] The writers have neither constructed nor used ebulliometers of these types.

Removal of Moisture

If moisture is to be removed from the substance under examination by heteroazeotropic distillation, the condenser system consisting of elements D and E is operated in the

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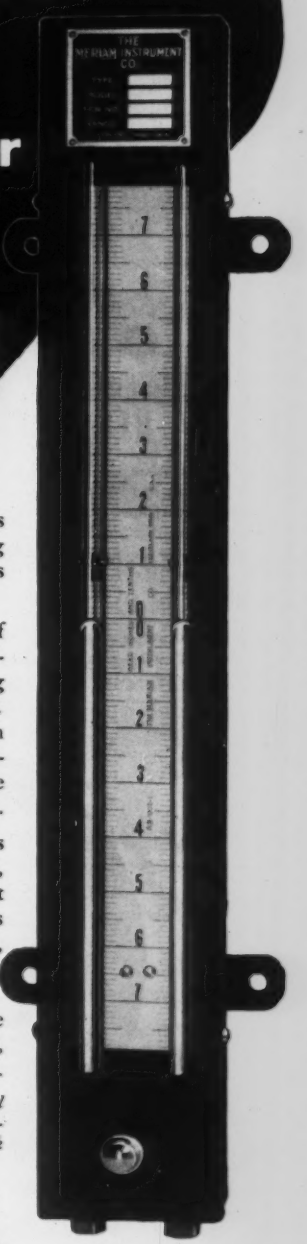

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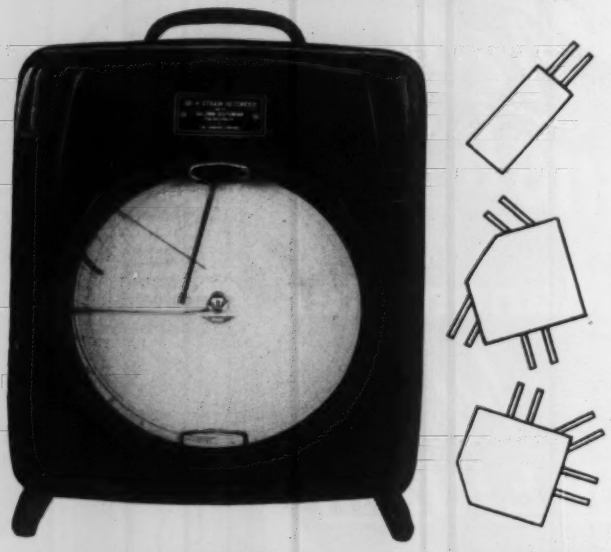

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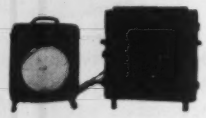

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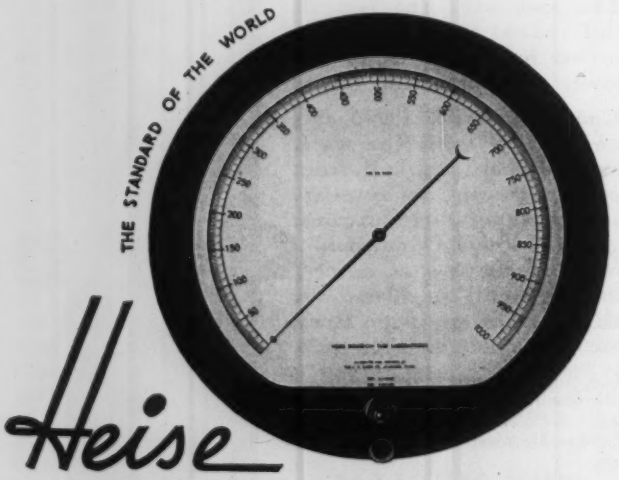

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following way: First, coolant is circulated in both D and E; second, when the moisture has accumulated in D, the coolant is removed from the latter and the vapors are allowed to rise until they are just condensing in E. Third, coolant is quickly reintroduced into D and the whole procedure repeated. Finally, coolant is removed from *both* D and E and, as soon as the vapor has penetrated all the way down to the receiver, coolant is quickly circulated, first through D, and then through E. The receiver (element H) may now be replaced by a drying tube. The whole operation, which may be repeated if necessary, usually requires the removal of two or three milliliters of the sample under examination.

Insulation

As a rule, it is desirable that the numbers of drops passing the drop counters located in the various parts of the apparatus should be the same or nearly the same. Usually, only a fraction of the heat-loss (through the insulation) can be compensated for by heating the U-tubes which return the condensate to the condensation-temperature elements. For this reason particular attention should be devoted to the problem of adequate insulation of ebulliometers, especially when the latter are differential or multistage, and where high-boiling substances are the objects of investigation. We prefer to use asbestos-paper tape* together with ⅛″ asbestos cord† as the insulating materials. After having been soaked with water, the cord is wound on as the first layer; this is followed, successively, by two or three layers of tape, also water-soaked, by another layer of cord, and, finally, by another layer or two of tape. If the subjects of measurement are liquids boiling much above 100°C., it is advisable to insulate the boiling-temperature wells further and to wind some nichrome resistance ribbon onto the top layer of tape on the condensation-temperature wells and rectifying sections. The ribbon, which should also be covered with cord and tape, can be used as an auxiliary electric heater for the introduction, even during the measurements, of a predetermined amount of heat into the insulation.

After acquisition of the requisite minimum of skill, it becomes possible to wind the wet cord over the irregular parts of the apparatus in a *uniform* layer. For insulating such parts, however, it is convenient to work with short pieces of the cord.

Electric Heaters

Electric heating-wires should be wound around the cylindrical boiler of element A and around the left half of the U-tube of condensation element B, and, of course, any one of a variety of materials may be employed for this purpose. We prefer to use, in both heaters, Nichrome wire having a resistance of approximately four ohms per foot. About ten feet is usually required for the boiler of element A and about one foot for the U-tube. Both heaters should be connected to an ammeter and appropriate fuse, and should be controlled by an autotransformer. The resistance wire is first insulated with approximately 1/16″ asbestos tubing* and then wound onto the boiler or U-tube. When winding the boiler it is more convenient to begin at the bottom (by looping the end of the wire under the first turn) and then winding upwards; the top end of the wire is then looped under the last turn. The tubing containing the resistance wire is then covered with several layers of asbestos-paper tape and, then with one or more layers of asbestos cord. Insulation should cover the entire boiler even though the resistance wire may not. For winding the U-tube, it is usually more convenient to start at the bottom of the U-bend: the asbestos tubing is covered by wet asbestos paper, only, and this is then molded with the fingers to the desired shape and thickness. It is scarcely possible to cover the U-tube heater with asbestos cord, owing to considerations of tube size and cord thickness.

The insulated boilers should be made first and then dried in an oven, before the elements are assembled. In this way, the boilers may be used for heating a liquid whose condensation will facilitate drying of the ordinary insulation.

*Keasbey & Mattison Co.
†Johns-Manville, Inc.

Ebulliometers of the Original Swietoslawski Design

Many American investigators have used simple and differential ebulliometers based on Swietoslawski's *original* design for molecular-weight work and for obtaining *dt/dp* data by the comparative, dynamic method. Fig. 188 is a photograph of a pair of ebulliometers of this type—simple and differential, respectively—adapted especially for molecular-weight work. Element E (Fig. 185) may be used in conjunction with these devices. For collection of *dt/dp* data, the side-arm of the differential ebulliometer, and the stopcocks of both ebulliometers shown in Fig. 188, are usually removed and element E is sealed directly to the condensers. The thermometer-wells of these apparatuses have been built to accommodate either short-stemmed Beckman thermometers as modified by Swietoslawski, or platinum-resistance thermometers. The latter have usually been employed in *dt/dp* determinations.

B. Construction

The construction of ebulliometer elements and accessories for different ebulliometric arrangements is not difficult if the fundamental techniques of glass manipulation have been mastered. Basically, ebulliometers consist of four distinct parts, the boiler, thermometer well, condenser and the condensed liquid drop counter. It will be helpful to describe the construction of the above parts in order to point out details which require critical attention.

The Boiler

The production of a boiler which will give smooth boiling with a minimum of superheating is essential in any apparatus in which the boiling of a liquid constitutes the major operation. Even though smooth glass surfaces are employed Small capillary cavities which are formed in this sintering in the majority of cases, such surfaces cannot be expected to give smooth boiling. Activated boilers can be made quite easily by fusing small glass particles to the boiler surfaces. process serve as active points for vapor formation and con-

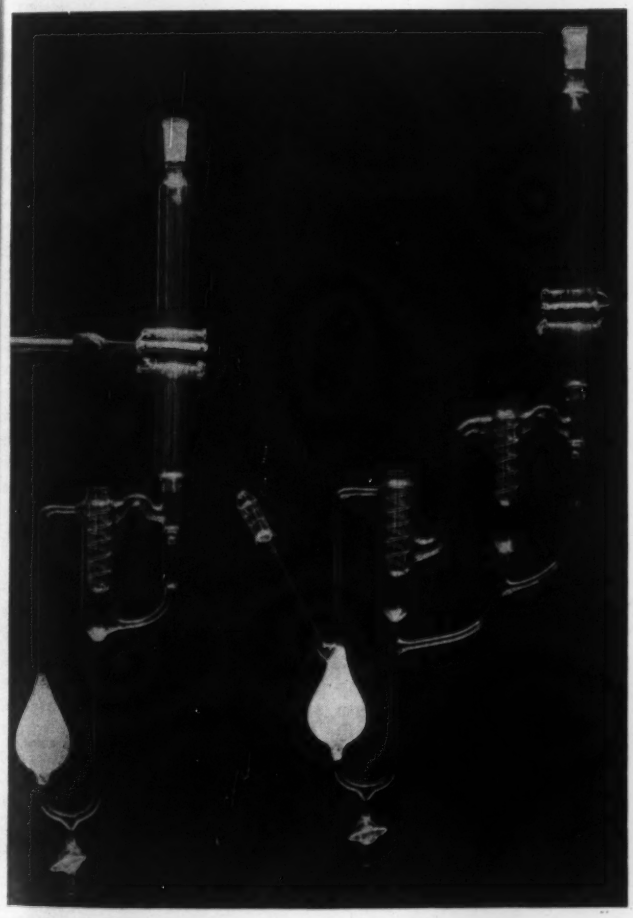

Fig. 188

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sequently smooth boiling is obtained with a minimum of superheating.

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Sintered Glass Boilers

Sintered cylindrical glass boilers are made as follows:

1. A cylindrical boiler with the shape and dimensions shown in Fig. 175A is filled with 50 to 60 mesh glass. This glass is held in the boiler by two glass wool plugs. The packed tube is then chucked in a lathe and the boiler is progressively heated from one end to the other. It is important to heat the tube to the temperature which will just fuse the pulverized glass to the boiler tube. If the tube is heated too hot, the edges of the small glass particles will become smooth and the powdered and fused glass will collapse, closing the small capillary cavities. The remaining loose glass powder is removed and the boiler is then annealed. If a lathe is not available, the operation can be completed by using supporting rollers.

2. Pear-shaped boilers for the ebulliometers shown in Fig. 188 are sintered by using just enough 50 to 60 mesh glass to cover the required surface in the boiler bulb. This pulverized glass is poured into the boiler which is then heated and rotated in a burner flame. As it approaches red heat, the loose powdered glass in the bulb will stick to the walls. A uniform coating of the small glass particles is obtained by rotating the boiler to build up the desired layer of sintered glass. Again, it is important to heat the boiler to the temperature which will just fuse the glass particles to the surface.

Thermometer Well Construction

Three different forms of thermometer wells have been illustrated in the ebulliometer elements discussed in this article. The length of the wells will depend on the thermometer which is to be employed. Construction details, however, are the same regardless of the size of the well.

The thermometer well of the element in Fig. 175A consists of the well with a tapered open end, a baffle tube and the outer jacket. The well is made by first closing one end of the tube. The open end is then reamed to shape with a standard taper. The depth and size of the taper will depend on the size of stopper to be used on the thermometer. All tapered ends should be the same size. The end of the taper is spun into a flare for the flare seal. The well is then ring-sealed to the baffle tube and a liquid and vapor inlet hole is blown into this tube below the ring seal. The well and baffle tube are then centered in the outer tube and held in place with glass tape pads. The flare seal is made. The glass at the tapered end is periodically tooled with the standard taper during this operation. Immediately after the flare seal is completed, the vapor outlet tube is sealed to the outer tube exactly opposite the liquid and vapor inlet in the baffle tube. The flare and vapor tube seals are then annealed.

The thermometer well, Fig. 175B, is constructed so that the vapor passes up between the thermometer well and the baffle tube and then downward through the annular space between the baffle and outer tube. In this case the tube of the well, the baffle tube and the tube of the outer jacket are all tapered. A flare is spun at the open tapered end of the thermometer well. The baffle tube is ring-sealed to the outer tube. The tapered end of the baffle tube should be about 5 mm. below the end of the outer tube. The side arm is sealed to the outer tube as soon as the ring-seal is completed. The glass is then annealed at these seals. The thermometer well is then centered in the element and the flare seal is made and annealed.

The thermometer wells in the ebulliometers shown in Fig. 188 differ from those previously discussed in that a glass

spiral is fused to the well. This spiral favors better thermal equilibrium between liquid and vapor because the liquid on the thermometer well must flow along the spiral.

The thermometer well is made as follows:

1. Points are pulled on both ends of the tube which is to serve as the well. A shoulder is blown on this tube for the ring seal. A 5-mm. glass rod is then fused to the tube just below the shoulder. The tube is turned with the point held in the left hand. The rod is heated with a burner flame and as it becomes pliable it is wound around the tube. The spiral should touch the well at all points. When the desired spiral length is obtained, the rod is fused to the tube and the excess glass is cut with the burner flame. Immediately after this operation, sections of the spiral are heated white hot progressively from this point until it is fused to the well. It is important that the rod be heated only to cause fusion at the point of contact on the tube; the rod should not be deformed in any way or the maximum liquid exposure area will not be obtained. A blow-tube on the point held in the left hand is used to blow out the glass in the well should it be accidentally collapsed. The tube at the end of the spiral is then cut and closed. The well is then annealed.

The well is sealed into the outer tube by the procedure illustrated in Fig. 41. The two side arms are then immediately sealed to the outer tube.

Drop Counters

The construction of drop counters has been previously described and illustrated in Fig. 43. The drop counters in all elements should be as near alike as possible. The maximum diameter of the glass hemisphere should be 8 mm. The flat plane of the hemisphere should be perpendicular to and centered in the counter tube.

Assembly of Ebulliometer Elements

The ebulliometer elements are assembled either by sealing together the tubes of the desired elements or by using ground glass joints. The former method of assembly is recommended because of the disadvantages of using ground joints without lubricants. The elements are assembled by clamping them to a rack and sealing them together with a hand torch. If ground joints are used, they should be of the No-Lube type.

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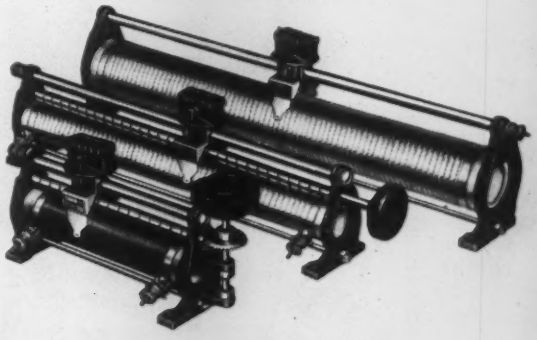

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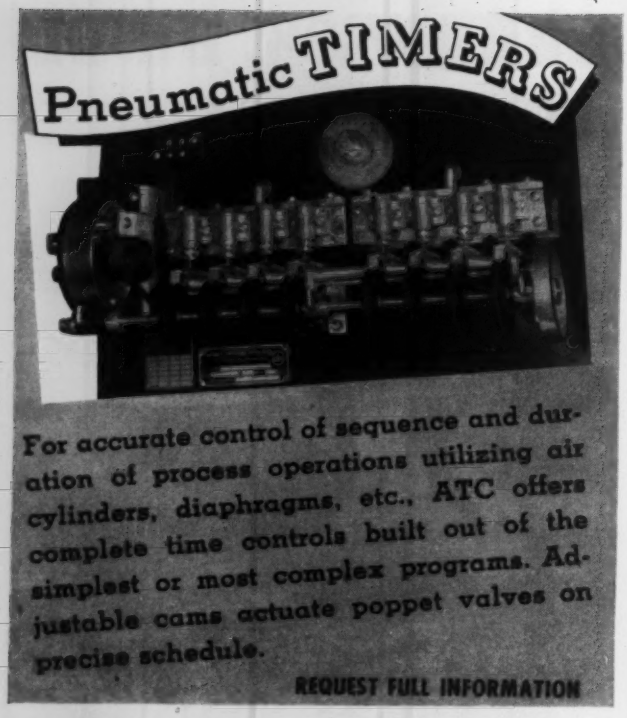

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The reader may regard the idea as unorthodox and think that it will only work in a very rare instance, but if he tries it he will find that it will work more often than it will not work; and he will save himself or his company costly coil replacements.

Blackening Etched Graduations on Glass Equipment

By LEON SEGAL, New Orleans, La.

LOSS of pigment from etched graduations on glass equipment, particularly thermometers, is disconcerting and the use of pencil carbon is a poor and inadequate makeshift for the original pigment. Ordinary black lacquer of the nitrocellulose type has been found to be a satisfactory coloring material. Thermometer scales that have been blackened with it stand up well after long immersion in water; organic solvents, however, attack the black lacquer.

The lacquer is applied with a small camel's-hair brush particular care being taken to brush it well into the etched portions. That other areas of the equipment become coated is not a matter of concern, as the excess lacquer will later be removed. Several coats are applied to build up quite a thickness of lacquer and the coating is then allowed to dry. Removal of excess lacquer is accomplished by lightly and carefully rubbing with a cloth dampened with acetone or by carrefully scraping with a razor blade, leaving undisturbed the coating in the etched portions. (If, however, any of the desired lacquer is accidentally removed, the process can be readily repeated.)

Application of black lacquer in the manner described can be made to thermometers, burettes, pipettes, etc., that is, to any glass equipment where a clear, sharp line of color is desired. The lacquer is inexpensive, has good lasting properties, and can be easily reapplied when necessary.

An Improved Funnel Design

By LEON SEGAL, New Orleans, La.

A USEFUL improvement on funnels for transferring liquids is obtained by cutting off most of the stem of a Pyrex funnel and sealing on a standard-taper ground-glass joint. Since no reference to such design has been seen in the literature it is believed worthy of description.

The advantages of using such a funnel are several: A stable funnel-bottle combination is achieved in which the funnel does not tip or move when used for filling flasks and bottles. There is no funnel stem immersed in the liquid. If the bottle has been overfilled, the excess liquid instead of overflowing from the bottle as with the usual funnel, merely fills the funnel. Liquid is not wasted and when permissible, can be poured back into the original container. The funnel does not have to be raised to allow air to escape from the bottle, the diameter of the joint being large enough to let air pass up through the center while the liquid passes down the wall. The result is a funnel that permits much faster flow than any yet used.

The 65-mm. and the 100-mm. size Pyrex funnels sealed to 24/40 ground joints have proved most satisfactory for average use. The ground joint is cut off about ½" above the ground portion and the funnel stem is removed; the funnel is cut high enough to allow easy mating with the joint. The two pieces are heated in a large gas-oxygen flame until they are both quite soft; they are then joined using slight pressure. No attempt is made to "blow" the joint, care being used, though, that the seal is complete and without pinholes. Careful annealing will remove strains and the resulting joint is strong enough for most purposes.

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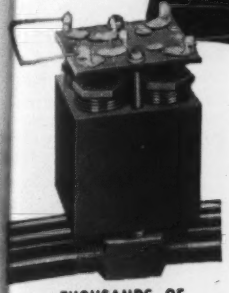

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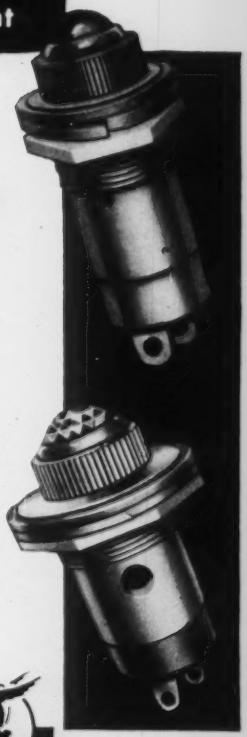

The Series 1110 Indicator Light comes in styles to accommodate either the long bulb or the small round bulb. Unscrew the jewel on the front and there's the bulb—no need to mess around behind the panel. All brass construction except nut and lock washer. Parts heavily plated. Not affected by heat. Furnished with famous Gothard rigid, non-short terminals; fibre space washer; lock washer and nut. Requires 11/16" mounting hole. Jewel is ½" dia., either faceted or smooth glass; colored red, green, amber, blue, opal, clear.

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The Month's NEW INSTRUMENTS

In this department we report each month new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

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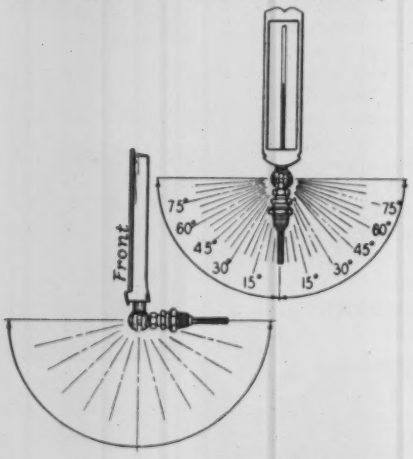
Adjustable-angle Industrial Thermometers

New "Adjust-Angle" thermometer is said to embody "the first important basic improvement on industrial angle thermometers in decades." Bulb may be

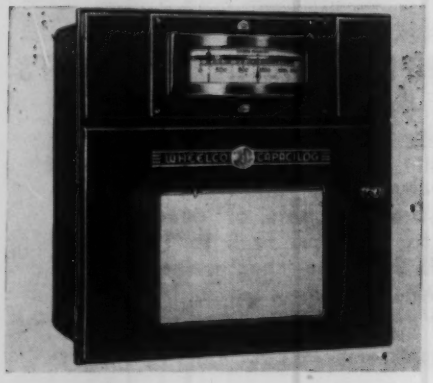


positioned at any angle (right or left side, front or back) with respect to scale-case, by "a simple turn of a lock nut." Plastic-tube connection between bulb and reading-column portions is said to have been perfected so that disadvantages of previous attempts have been overcome. For example, effect of maximum change of bore volume between extremes is negligible (a small fraction of National Bureau of Standards' tolerance) so that accuracy is not impaired. New thermometers are available for all usual industrial applications, with any standard connections and fittings in any standard material.—*Weksler Thermometer Corp., 52 West Houston St., New York 12, N. Y.*

Please mention number 901 when filling out card

Recorder-controller

New "Capacilog" strip-chart recorder and automatic controller operates on "electronic principle" utilized in company's "Capacitrol" pyrometer control-

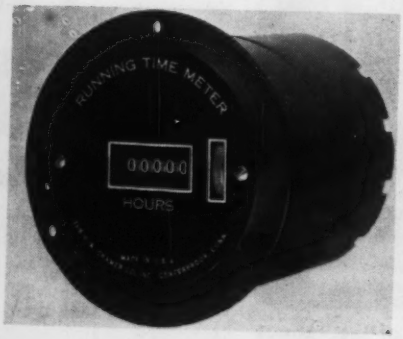


ler. It is designed for indication, control and permanent record of variables in process industries. It is available as a deflection, potentiometer or resistance thermometer type recorder, recording controller or indicating controller. A "Positive-power-driven Pen" is added to "Electronic Link" between measurement and control for deflection and null-method types of measuring systems. It is claimed that simplicity of operation without amplification, physical contact or disturbance in measuring circuit results in accurate and instantaneous response. Simplicity of design, with a minimum of moving parts and front-accessibility throughout, results in ease of service and maintenance. "Capacilog" operates on 115- or 230-volt, 25, 50 or 60 cycles, is available in a number of models utilizing a variety of control systems. Maximum power consumption: 60 watts. — *Wheelco Instruments Co., 847 W. Harrison St., Chicago 7, Ill.*

Please mention number 902 when filling out card

Running-time Meter

New Time Totalizer or Running Time Meter features a counter that can be reset to zero. Designed for use on a-c. circuits, meter registers total operating or idle time of any circuit, ma-



chine or system to which connected. Precision-built five-digit cyclometer registers in tenths up to 10,000 hours, then repeats. Three models: "Type E5" for table use; "Type E6," enclosed in metal housing arranged for conduit connection, complete with hinged cover and hasp for padlocking; "Type E7" (illustrated) is a 3¾" diameter instrument in combination die cast and Bakelite housing for flush panel mounting, is equipped with knob reset accessible from front. Cramer Synchronous Motor used in these meters, of the slow-speed self-starting type, will start and operate satisfactorily on rated voltage plus 10%; are provided with an adequate supply of sealed-in lubricant and require no special attention.—*R. W. Cramer Co., Centerbrook, Conn.*

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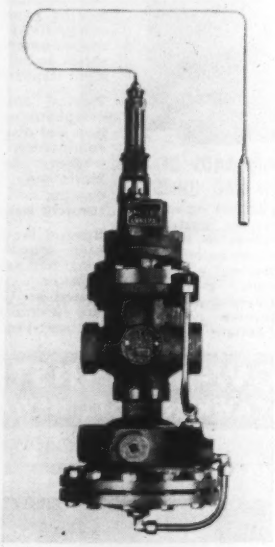
Self-operating Temperature Controller

New "Class T Self-acting Temperature Regulator" has been designed to provide temperature control at low cost. Features include single-seated construc-



tion in all sizes, packless main valve stem, hard-faced seating surface and hardened wearing parts, positive dead-end shut-off. Sizes available are ½" to 4" inclusive for steam pressures to 125 lbs./in.² (175 lbs./in.² liquid) and temperatures to 450°F.—*Leslie Co., 225 Delafield Ave., Lyndhurst, N. J.*

Please mention number 904 when filling out card

Furnace Temperature Controller

New "Alnor Electronic Pyrometer Controller" for automatic heat control of furnaces, melting pots, kilns—any heating device using electricity, gas or

il—is designed for both production or laboratory operations. Pyrometer movement is double-pivoted on jewelled bearings; 6″ mirrored scale is easy to read; case is dust-tight and weather-proof. Ruby "eye" indicates ON and OFF conditions of heat supply. — *Illinois Testing Laboratories, Inc., 420 N. La Salle St., Chicago 10, Illinois.*

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Pressure Switch

New "Hi-Pressure" switch is available in any of four operating ranges: 5-50, 50-200, 200-500 and 500-2000 lbs./in.². Differential between ON and OFF is approx. 10% of operating pressure. Switching mechanism is housed in im-

pregnated-aluminum casting. Metal parts are cadmium-plated where necessary. Max. current capacity, 10 amps. at 115 volts a.c. Pressure connection in six pipe sizes. Weight, 2 lbs. Switches are factory-calibrated but a calibration screw is provided for adjustment.—*Cook Electric Co., 2700 Southport Ave., Chicago 14, Ill.*

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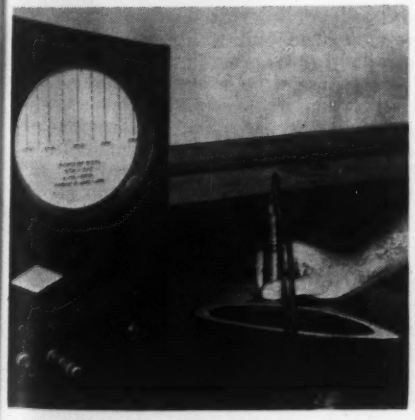
Supersonic-type Thickness Gage and Flaw Detector

New "Reflectogage," utilizing supersonics for thickness measurement and flaw detection, supplement maker's "Supersonic Reflectoscope" and "Thru-



ray." It permits measuring thickness of metals and other materials from only one side. Accuracy 2% thickness of material. Thickness of tubing and flat parts, between 0.005″ and 0.300″, can be read directly from face of oscilloscope screen. Indirect reading of thickness of parts up to 4″ can be accomplished with slight calculation. "Reflectogage" is adaptable also for production line testing of thin pieces, or bonded or clad materials, for internal defects or separations.—*Sperry Products, Inc., 15th St. & Willow Ave., Hoboken, N. J.*

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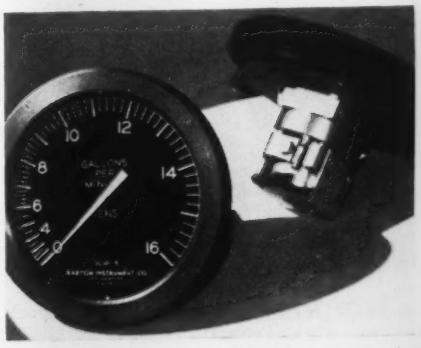
New line of servomechanisms is announced, each specifically engineered for its specific job, hence none available from stock. However, standardization of principal components permits rapid assembly after completion of quantitative dynamic analysis. Company offers consulting surveys in automatic control with or without subsequent development and manufacture: products of established instrument manufacturers may often be recommended instead of resorting to new designs. Announcement states that new company does not compete with manufacturers of controllers, regulators, etc.—*Industrial Servomechanisms Inc., 53 State St., Boston 9, Mass.*

Please mention number 908 when filling out card

Differential-pressure Gage

New "Model 181 Differential Pressure Indicator," for measurement of flow, liquid level and pressure differen-



tials, features a 6″ dial for easier visibility; wide differential pressure range (0-50″ water up to 0-200 lbs./in.²); universal mounting and an improved vapor-proof case. "Model 181" is constructed of drawn bar stock and has brass rupture-proof bellows. Static pressure ratings extend up to 3000 lbs./in.². Dimensions, 7½″ diameter, depth 4½″. — *Barton Instrument Co., 3500 Union Pacific Avenue, Los Angeles 23, Calif.*

Please mention number 909 when filling out card

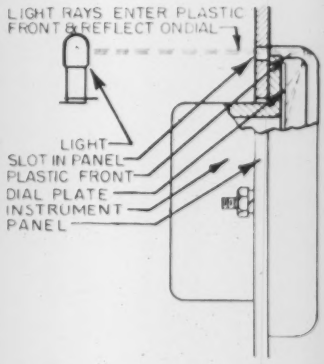
Bellows-seal Valve

New "Bellows Seal Valve," for handling and controlling gases, is of a new type said to have many uses such as precision fluid flow control in vacua without atmospheric leakage, controlling gas flow in conjunction with mass spectrograph, controlling admission of rare gases into high-vacuum tubes and other electronic devices, etc. Special features include: Retraction of valve spindle is positive, being controlled by an independent spring action supplementing normal bellows retraction. The entire valve being hermetically sealed by silver brazing precludes any contamination from atmosphere.—*Hoke, Inc., Englewood, N. J.*

Please mention number 910 when filling out card

Illuminated-dial Electrical Instruments

New method of rear illumination of electrical instruments is available for three models: "Models 352" for a.c. and



"351" for d.c. are 3¾″ rectangular; "Model 103" is 1″ diameter round.—*Assembly Products, Inc., Chagrin Falls, Ohio.*

Please mention number 911 when filling out card

Flammable Vapor Detector

New "Thermalo Flammable Vapor Detector" consists of one or more detector cells, placed where flammable vapors are likely to accumulate, and an instrument control case located at any desired distance from cell or cells. Models are available for fixed installation or for portable use. Field of application includes carriers (ships, barges, conveying systems) employed for plant deliveries. Continuous sampling of atmosphere is effected automatically—either by direct sampling or by draw-off. (Most applications are non-aspirating.) When percentage of flammable vapor in atmosphere sampled reaches a predetermined percentage of lower explosive

limit of the vapor, relay in instrument case is activated, signal lights flash and other alarms or safety controls may be operated automatically. Failure of current or of any element in mechanism also actuates alarm circuit. Dial for continuous indication of concentration of vapor in air mixture, showing percentage of lower explosive limit, can be furnished. Standard instruments operate on 100-120-volt 60-cycle a.c.; special units for other voltages and frequencies or for d.c. are available.—*Jabez Burns & Sons, Inc., Eleventh Avenue at 43rd Street, New York 18, N. Y.*

Please mention number 912 when filling out card

Pneumatic Gages

New complete line of pneumatic gages, known as "New-Matic," features exclusive "reversed-flow" principle which provides both a calibrated measurement scale of required magnification and a zero adjustment for basic value. Gages are equipped with continuously-variable and adjustable orifices, making posible control of air volume, as well as

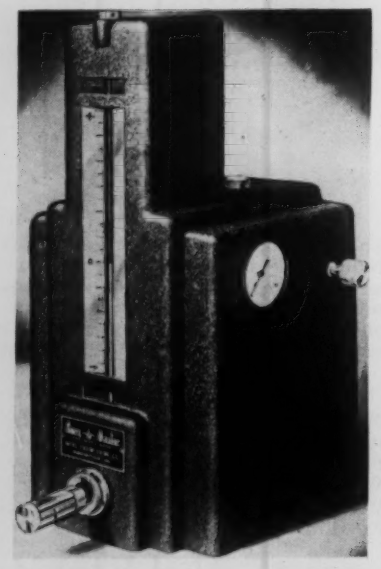


Fig. 1

air pressure, and providing "balanced air" for high-precision measurement. Thus, they are not merely comparators but measuring instruments. Variations from standard dimensions are shown on scales or dials in graduations to meet customers' requirements. "New-Matic" gages are made in five models to fit inspection requirements of every type—in gage laboratory, on high-speed production operation, for checking finished dimensions at machines. Standard calibrated scale available for any required magnification up to 20,000 ×. Normal scale covers 0.004" and magnification of approx. 1,000 ×. Standard and special accessories, equipped with synthetic ruby contacts and tungsten carbide inserts, make use of Setting Masters unnecessary. Operation requires no special training or technical knowledge. Air consumption is said to be excentionally low. Fig. 1 shows "Model 10 Master Measuring Machine" with 1" diam. two-button gaging plug. Fig. 2 shows "Special New-Matic Taper Gage" for both taper and out-of-round. Taper gages consist of two "New-Matic"

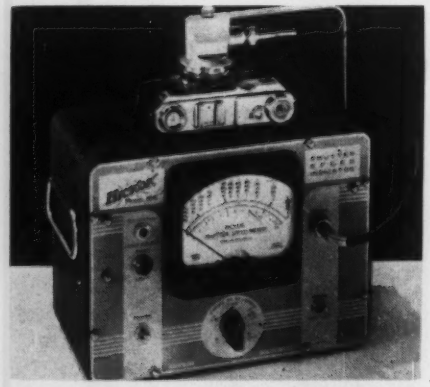
Fig. 2

gages equipped with a fixture incorporating large and small taper-gaging rings of hard steel. Taper variations are registered on one gage to ±30′ in graduations of 5′ (or if preferred, to ±10′ in 1′). Out-of-round condition is shown on second dial in graduation of 0.0001" to a total of 0.002".—*Merz Engineering Co., 200 South Harding St., Indianapolis 7, Indiana.*

Please mention number 913 when filling out card

Camera Shutter Speed Indicator

New Shutter Speed Indicator is the first ever offered. It was developed primarily to detect shutter speed inac-



curacies in cameras used for color work where slight shutter error makes a much greater difference in final photographic results; but most cameras tend to develop shutter speed inaccuracies owing to climate, age and use.—*The Hickok Electrical Instrument Co., 10519 Dupont Ave., Cleveland 8, Ohio.*

Please mention number 914 when filling out card

X-ray Unit for Stress Analysis

New x-ray diffraction unit with back-reflection instrument can be used in field, shop or laboratory work; is particularly suitable for stress analysis, such as in determining residual stresses in welded plates on board ship or checking for fatigue cracks in bridges and other structures. Equipment consists of: (1) generator with meters and controls; (2) pump for circulating and cooling water; (3) x-ray tube mounted on a flexible tube stand. Unit is self-rectified and shock-proof; tube is ray-proof. For work on steel it is equipped with a cobalt target. Back-reflection camera is mounted to tube window. Circular film holder is oscillated during

exposure by a small motor also mounted on tube base. Unique feature of this method is that x-ray beam falls through center of film onto object, from which it is reflected back to film where it registers a pattern. This pattern serves to calculate existing stresses. Unit is portable and comparatively simple to use.—*St. John X-Ray Laboratory, Califon, N. J.*

Please mention number 915 when filling out card

Water Controller for Welding

New "Weltronic Water Saver" relieves operator of any welding machine of duty of turning on or shutting off cooling water in a welding operation, is

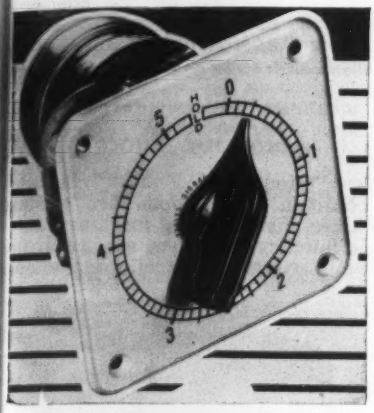
so designed that its two control relays and solenoid-operated water valve are de-energized if welding machine is stopped for longer than 30, 60 or 90 seconds (three time ranges available). De-energizing water valve stops flow of cooling water; starting welding machine energizes initiating transformer. Installation of "Water Saver" reduces condensation, avoiding transformer shorts; cuts water use during idle time; eases overloaded disposal systems, with a saving to pumps; decreases mineral deposits, repairs and down time; reduces sweating, rust and corrosion, and avoids community water famine in dry months. All components of "Water Saver" are mounted on a panel easily removable for inspection. Two Type 2D21 thyra-

trons and two relays are employed in control circuit. Standard units have delay time of 30, 60 or 90 seconds. Power supply is 115, 280 or 460 volts, 60 cycles, single phase.—*Dep't K, Weltronic Co., 19464 W. Eight Mile Road, Detroit 13, Mich.*

Please mention number 916 when filling out card

Manually-controlled Automatic Timer

New "Manuflex" is a manually-controlled automatic timer for machines such as washers, chargers, extractors,



etc., which are turned ON and run a predetermined time. It is synchronous-motor-driven. Other features: heavy-duty silver contacts; flush mounting from front panel; screw terminals—no soldering for wiring connections; "HOLD" position (switch ON without timing) optional.—*Eagle Signal Corp., Moline, Illinois.*

Please mention number 917 when filling out card

Stiffness Tester

New motor-driven stiffness tester is designed for rapid, consistent, and accurate tests on thin flexible sheet materials. Its capacity is from light tissue paper or thin cloth up to heaviest single-sheet boxboards in common use, also for light-metal and foil testing. Balanced pointer pivots in jewel bear-

IT'S VERSATILE—Used for detecting and diagnosing trouble in nearly all types of electrical equipment including: motors, generators, transformers, switchboards, appliances, lighting circuits, meters and relays . . . practically *everything* electrical.

IT'S EASY TO OPERATE—Simply make connections, turn the crank and take a direct reading. It's as simple to read as a voltmeter. Ratings up to 50 megohms, 500 volts.

IT'S CONVENIENT—Requires no external power supply, no adjustments, no batteries or replacement parts. DC test current is supplied by a self-contained hand-operated generator—an unfailing source, *always* ready for use.

IT'S INSURANCE—Insulation testing with a "Megger" Tester is your first line of defense in electrical preventative maintenance . . . your protection against moisture and other enemies of electrical insulation . . . a *must* in your struggle for uninterrupted electrical service.

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READ THIS BULLETIN . . . Here's the ABC of the Midget "Megger" Insulation Tester, telling briefly and in common sense language just what the Midget "Megger" Tester is, how it is used . . . AND . . . what it will do for you. Write for your copy of Bulletin 1785 -I *today*.

James G. **BIDDLE CO.**

ELECTRICAL & SCIENTIFIC INSTRUMENTS

1316 ARCH STREET • PHILADELPHIA 7, PENNA.

ings and traverses a sine scale. Tester is loaded with weights of 5, 25, 50, or 200 grams, fastened 1", 2", or 4" from the pivots. Arm carrying the sample is moved by a synchronous motor controlled by a reversing switch on base. Sample is first cut to a standard width and length: clamped so that free end overlaps top of pointer by ¼"; and pressed against top of the pointer until it is bent sufficiently to assume a short arc, shortening it by ¼" overlap. Pointer is then automatically released. Greatest reading of pointer against sine scale is averaged in both directions, then may be multiplied by a factor applying to one of 144 combinations of sample and loading weight: product is expressed as stiffness of sample.—*W. & L. E. Gurley, Troy, N. Y.*

Please mention number 918 when filling out card

Multi-speed Kymograph

New "Mono-Drum" (Fig. 1) has 22 instantly selectable speeds, from 0.0296 to 575 inches per minute (0.075 to 1460

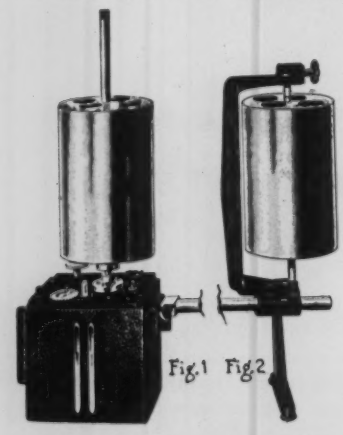


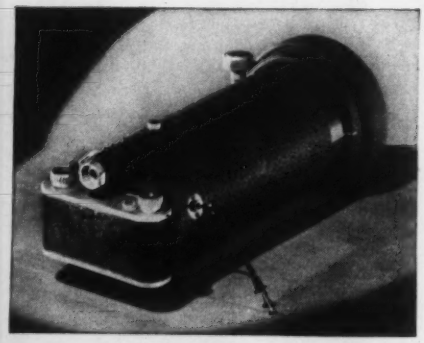
Fig.1 Fig.2

cm./sec.), steps being relatively small (ratio of 1.6 to 1). All-aluminum drum has 6.25" diam. giving 50-cm. circumference; standard height (chart width) 10"; 20" and 30" drums also available. Exclusive features include sparkless synchronous motor which can be stalled or overloaded without danger. "Mono-Drum Extension" (Fig. 2) converts "Mono-Drum" into a two-drum kymograph taking paper from 42" to 150" long and up to 10" wide.—*Gorrell & Gorrell, Haworth, N. J.*

Please mention number 919 when filling out card

Oscillograph Camera

New "Type 271-A Oscillograph Camera" is a simplified unit which does not require that recordings be taken in a darkened room in order to obtain adequate contrast. It clamps on usual supporting ring of c-r. tube of any standard 5" oscilloscope, is positioned for correct focus. Adjustable mounting permits camera to be horizontal, vertical or tilted. "Type 271-A" is a 35-mm. camera with fixed-focus *f*/3.5 coated lens and simplified shutter with Time. Bulb and 1/30 second. Screen image is observed through peep-hole at camera end of rugged light hood, and exposure made by conventional cable release. Camera,



held on light hood by bayonet lock and spring detent, is instantly removable for shutter and lens settings, also for convenient loading and unloading of film spools. Rubber rim on front end of light hood presses firmly against c-r. tube face in positioning camera for correct and fixed focus but will not scratch tube. Instructions supplied with camera help determine proper exposure.—*Allen B. DuMont Labs., Inc., Clifton, N. J.*

Please mention number 920 when filling out card

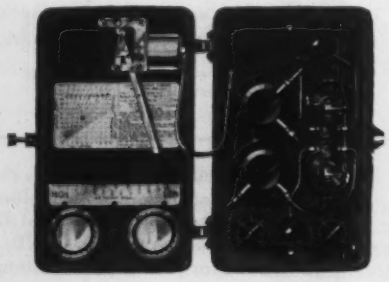
Optical Pyrometer Lens

New objective lens assembly makes size of image which an operator sees in L&N Optical Pyrometer twice as large as standard instrument provides. This increased size is particularly useful in measuring temperature of thin or small-area objects. It makes brightness match between hot object and Optical's disappearing-filament considerably easier to obtain, in cases where target would otherwise appear almost as small as filament. Typical applications: measuring tapping temperatures by sighting at darker streak at the center of tapping stream; reading temperature during spoon tests by sighting at narrow ribbon of metal pouring from spoon. Lenses are easily interchangeable.—*Leeds & Northrup Co., 4934 Stenton Avenue, Philadelphia 44, Pa.*

Please mention number 921 when filling out card

Dual-pilot Liquid-level Controller

New "Series 2406-248 Level-Trol" has two distinct pilot circuits, for process industry applications where it is

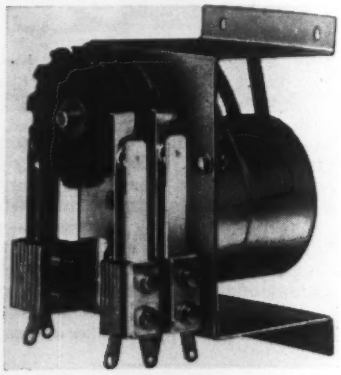


desirable and necessary to indicate (or record) as well as to control liquid level: where indication or recording is better separated from controlling function by a separate transmitting unit so that operator may change his level control point, or range of level operation, without disturbing his indications or records. New dual instrument can be installed and indicator portion set to indicate or record level over full float range and then locked in position: control function is handled by the second pilot, which may be adjusted without danger of disturbing indication or recording. "Series 2406-248" further offers a visual indication of level to the field operator through use of a clear-vision scale in case door. This scale is operated pneumatically by level indicator pilot only, therefore is not subject to being thrown out of calibration when controller adjustments are made. Both pilots are operated by one float-and-torque-tube measuring system.—*Fisher Governor Co., Marshalltown, Iowa.*

Please mention number 922 when filling out card

Automatic Timers

New "Model VF Timers," intended for built-in applications for vending machines, dish-washing machines, automatic laundry machines, etc., requiring time and sequence control, are available



from 1 to 6 circuits for 6, 24, 110 or 220 volts, 50 or 60 cycle. Contacts have a 10-amp. rating, can be supplied in single- or double-throw, slow make or break, or with snap action. Overall width approx. 2½", length 3⅝", height from 2½" for single-cam unit to 3⅝" for 6 circuits. Timers are equipped with maker's "Type SX" synchronous motor, are available in a variety of speeds from 1 rpm to 1/24 rph.—*The R. W. Cramer Co., Inc., Centerbrook, Conn.*

Please mention number 923 when filling out card

Comparator Microphotometer for Spectrochemical Analysis

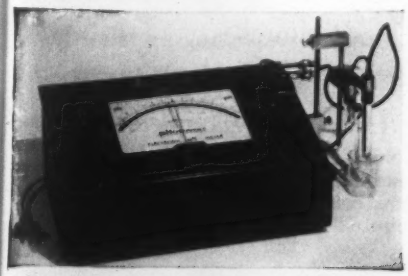
New Projection Comparator Microphotometer is said to provide unusually high sensitivity since full 500-cm. clear plate readings can be obtained for photocell slit widths corresponding to spectrum lines 20 microns with × 0.5 mm. long. A brilliant narrow field for photocell illumination, surrounded by a much-lower-intensity field for viewing spectrum, minimizes scattered light from spectrum itself, while instrument walls shield photocell from scattered room light. High sensitivity and freedom from scattered light enhance spectrograph resolution. Galvanometer readings are obtained from a projected scale

which moves across a fixed index, making it possible to increase speed of reading and reduce operator fatigue. Galvanascope may be used independently for applications requiring a self-contained sensitive galvanometer. —*Jarrell-Ash Co., 165 Newbury St., Boston 16, Mass.*

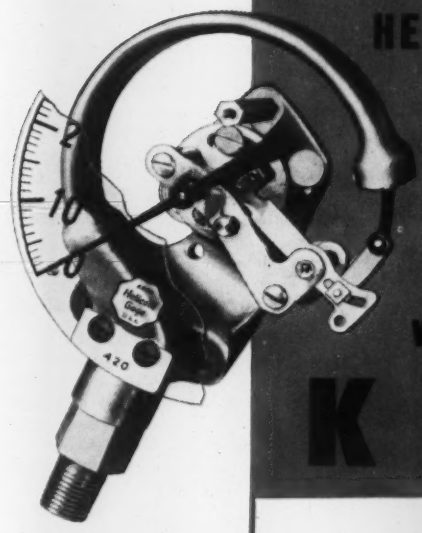
Please mention number 924 when filling out card

Line-operated pH Meter

New "Model 100 Electronic pH Meter" is said to combine high accuracy of a laboratory-type instrument with the ruggedness and simplicity of operation of an industrial model. Indicator has a 7" scale and mirror for high precision. New meter covers complete pH range, no reversal switch being required. It is always ready for immediate readings; is standardized with aid of a single buffer solution and a single control knob. A tell-tale hand marking reference point makes it possible to restandardize in the course of actual measurements without use of a buffer. Wide-range temperature control (0-100°C.) obviates necessity of consulting temperature correction charts. A voltage selector makes "Model 100" usable on any voltage between 90 and 275. Instrument is fully stabilized for line voltage fluctuations; can be left turned on continuously. "Model 100" is illustrated; "Model 105" is mounted on a baseboard, with an electrostatically-shielded compartment and a wooden hood with carrying handle: completely-enclosed portable unit; shielded compartment permits use of unshielded electrodes. Shape of standard set of electrodes makes it possible to carry out measurements on quantities as low as 5 ml. A variety of electrodes is available. Special adapters permit use of



electrodes of other makes and special designs. In addition to pH scale, dial has a millivolt scale from −400 to +400. Instrument can be used for continuous indication in titration work, no switching being required near zero point. Design and materials insure de-



HELICOID GAGE

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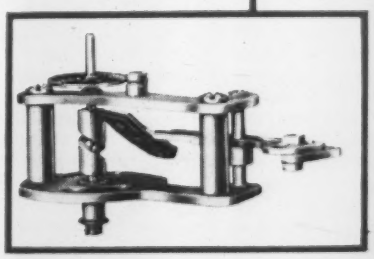
K MONEL

With superior spring characteristics and high resistance to corrosion, K Monel is unequalled for certain difficult pressure gage applications. In actual service under the worst corrosive conditions, such as Hydrogen Sulphide gas or oil, Helicoid Pressure Gages with K Monel Bourdon Tubes have remained accurate ten times longer than gages with stainless steel tubes.

K Monel Bourdon tubes are made of Korex tubing, with extra-smooth inside wall, for all pressures from 30 p.s.i. to 10,000 p.s.i.

- **These tubes are fused** to forged Monel sockets and tips—no solder, no welding rod—providing an integral Monel system. Heat-treated to obtain maximum spring properties in tube.
- **K Monel Gages cost no more** than stainless steel tube gages. Yet they are infinitely superior for prolonged accuracy and low hysteresis effect.
- **Try Helicoid Gages now** with K Monel tubes. Send for your copy of the new Helicoid Gage catalog.



The Helicoid Movement is one of many exclusive features of the Helicoid Pressure Gage.

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TRADE MARK

pendable operation under high humidity as in tropical climates. All tubes as well as a calibrating control (to be used after tube replacement) are easily accessible from rear of housing, without removing instrument panel.—*Photovolt Corp. 95 Madison Ave., New York 16, N. Y.*

Please mention number 925 when filling out card

Cabinet Mount for Electric Counters

New Panel-mounting Cabinet Unit houses and encloses five "Wizard Panelmount Electric Counters." Counters are connected and installed from front, making it practical to completely assemble and wire cabinet before counters are installed. (Counters are equipped with convenient terminal screws for easy connection.) Knockouts for conduit connections are provided in cabinets. Knockout holes for

Rear View of Counter showing Terminals for wiring connections.

bolts in sides, top and bottom make it easy to combine and mount any number of cabinets. Cabinet capacity for one hundred counters requires a space 56″ wide, 40″ high and 5½″ deep.—*Production Instrument Co., 702 W. Jackson Blvd. Chicago 6, Illinois.*

Please mention number 926 when filling out card

Pressure Controller

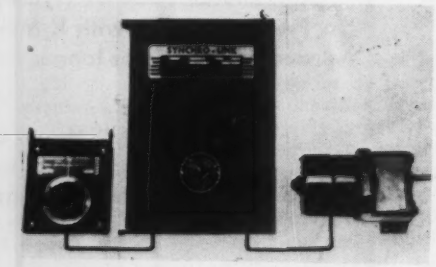
New "H-701 Pressure Control" may be mounted in any position, has a minimum of moving parts. Heavy-gage steel construction withstands shock; frame is cadmium-plated and cover bonderized to

resist corrosion. Visible scales provide finger-tip adjustment in range of 1-15 lbs. and differential of 1-5 lbs. Available for 110-volt-10-amp. or 220-volt-5-amp., single-pole, single-throw or double-throw, normally open or normally closed. Underwriters approved for ½-hp. rating. Extreme dimensions 3⅝″ × 3⅝″ × 2½″. Mfd. by Aerotec Corp.; distributed by *The Thermix Corp., Greenwich, Corp.*

Please mention number 927 when filling out card

Position-type Servomechanism

New "Type SL3 Synchro-Link" is a packaged remote-positioning servo control that will position one or several distant motors according to the setting of a master control dial. Accuracy is independent of load. Two adjustments are provided: Sensitivity control: A 3-position switch provides 0.5%, 1% and 1.75% accuracy; Anti-hunting (anticipating) control: a 4-position switch for extending range of anticipating over a suitable portion of full range and preventing undue hunting in event of heavy inertia load in the drive. These adjust-



ments are set for each application and do not have to be changed afterward. "Type SL3" works on principle of a self-balancing electronic bridge. It consists of three basic elements: (1) Master control with a knob and a calibrated dial for manual control or with ¼″ shaft extension for automatic control; (2) "Synchro-Link" electronic controller; (3) Load control voltage divider geared to the motor or coupled to the load. "Synchro-Link" controller contacts will handle up to 15 amps. 110-volt a.c. (10-a. 220-v.) non-inductive load. Any suitable 3-lead reversible motor within this rating can be connected. Provisions are made for adapting circuit characteristics to the particular motor and local conditions of load and inertia. Power of positioning motor is not limited. Three-phase motors up to 35 hp. and more can be controlled by connecting "Type SL3" to standard magnetic reversing starters.—*Yardeny Laboratories, Inc., 105 Chambers St., New York 7, N. Y.*

Please mention number 928 when filling out card

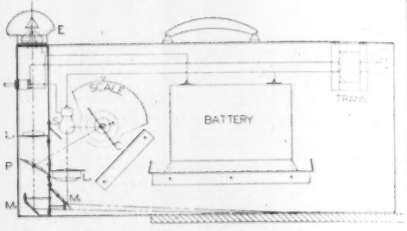
Self-quenching Geiger Tube

New rugged multi-purpose self-quenching Geiger tube for use with beta, gamma and soft x-radiation employs an extremely thin mica window which is vitreous-sealed to main tube body. Design is especially suited to tracer, survey and x-ray spectrometer work: essentially a tubular chr ne-iron cathode having a mica windo of high transmissibility at one end an a glass section for supporting anode t other end. Over-all length, 6″; diam ter 1″, length of metal cathode, 3¾″. node is 4⅛″ long and bears a glass be d at its free end. Mica window aver es approx. 3.2 mg./cm². Tube may e used for tracer work employing C^{14}, for soft x-radiation and for operations involving radium. Used with suitable circuits, it is capable of handling in excess of 3000 discrete counts per second. Threshold voltage is 1350 and plateau exceeds 300 volts in length. Normal operating potential is 1450. Laboratory tests indicate that this tube will have a life exceeding 10^9 counts. Quantum efficiency for soft x-rays is in the order of 70-80%.—*North American Philips Co., Inc., 100 East 42nd Street, New York 17, N. Y.*

Please mention number 929 when filling out card

Night Visibility Meter

New "Hunter Night Visibility Meter," first instrument of its type to appear, measures night visibility of traffic



paints and signs. It may be used in laboratory, or in the field in full daylight. Importance: two traffic paints may differ in night reflectance by a factor of FIFTY and two sign materials may likewise exhibit enormous differences. Also, "reflectorized" paints and signs can be tested under proper conditions. Operating principle (see longitudinal section): beam from 6-volt lamp S intersects surface of material at angle of 2.9° from grazing; viewing beam from operator's eye intersects surface at 1.7°; operator matches by rotating comparison panel C; then reads value on reflectance scale on outside of instrument. (Angles are those of automobile headlights and driver's line of sight.)—*Henry A. Gardner Laboratory, Inc., 4723 Elm St., Bethesda 14, Md.*

Please mention number 930 when filling out card

Universal Tachometer Head

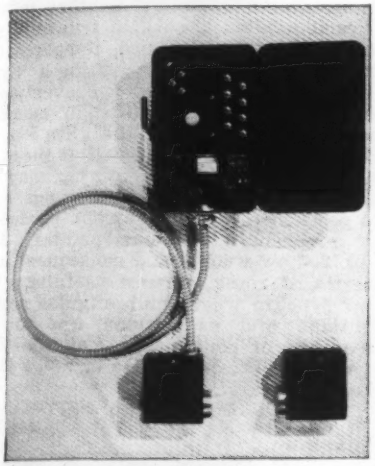
New tachometer head for all speed measurements between 100 and 10,000 rpm. contains only one rotating part, mounted in permanently-lubricated ball

bearings. Electrical connections are made through ½″ conduit or fittings to inside terminals. All parts are sealed against dirt. Heads can be operated in any position, are usable with any of maker's indicators or recorders. Direct coupling without need of a speed changing drive is provided for all speed ranges. Unit weighs 14 oz.; dimensions $2\frac{3}{16}'' \times 1\frac{15}{16}'' \times 5''$; operating torque approx. $\frac{1}{30}$ oz.-in. Mounting is provided by tapped holes in both bottom and end. New unit may be used with "Type 66" pedestal mount. — *Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.*

Please mention number 931 when filling out card

Photoelectric Control

New "Photoelectric Control Type 20DJ1" is said to be a high-speed, rugged, general-purpose control specifically designed for industrial applica-

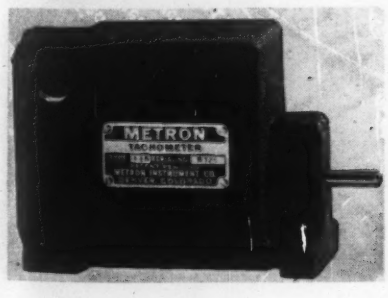


tion: counting, conveyor control, automatic paint spraying, break detection, automatic weighing, sorting, gate signals, etc. Phototube and light source lamp are in small dust-tight, die-cast housing, both wired to control housing. A tamper-proof sensitivity adjustment permits positive operation over varying distances from control to light source and under conditions of ambient light. Relay operates in $\frac{1}{20}$ second. Operating range is ten feet. — *Photoswitch Inc., 77 Broadway, Cambridge 42, Mass.*

Please mention number 932 when filling out card

Wide-range Tachometer Head

New "Type 53" tachometer head permits measuring low speeds (down to 1 rpm.) and high speeds (up to 100,000



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BRADLEY

PHOTO ELECTRIC CELLS

SIMPLIFY PHOTO-ELECTRIC APPARATUS

Luxtron* photocells convert light directly into electrical energy. No external source of voltage is required. Meters and relays can be operated directly from Bradley Luxtron photocells, improving control over manufacturing operations, reducing your costs. They meet the most exacting requirements. Advanced manufacturing techniques make light-actuated Bradley cells the choice all over the world.

Besides the housed model shown with its plug-in contacts, Bradley also offers tube socket, nut-and-bolt types and pigtail contact mountings. In addition, Luxtron unmounted cells are available in many different sizes and shapes.

*T. M. REG. U. S. PAT. OFF.

Illustrated literature, available on request, shows more models of Bradley photocells, plus a line of copper oxide and selenium rectifiers. Write for "The Bradley Line."

BRADLEY LABORATORIES, INC.

82 Meadow St. New Haven 10, Conn

rpm.) in conjunction with maker's electric tachometer indicators. A speed-changing gear drive built into new head features one-and-two-mesh spur-gear construction with permanently-lubricated ball-bearings on all shafts. Gears are steel and self-lubricating plastic and long-life is said to be obtained even without maintenance lubrication. Continuous operation up to about 75,000 rpm. is practical. "Type 53" is easy to mount, can be operated in any position, is 3⅝" high × 2½" × 5⅞" long.—*Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.*

Please mention number 933 when filling out card

Single-knob Type Control for Electric Motors

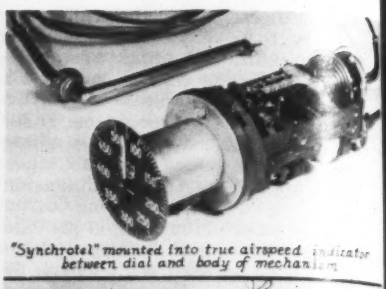
New "Type B Pulsing Drive" performs same basic functions as "Yardeny Pulsing Drive" (*Instruments*, February

1946, page 100) and "Yardeny System Pulsing Drive" (*Instruments*, December 1946, page 764) but with even more precise control, making it suitable for high-precision inching of machine tools, printing presses, conveyors, antennas, etc. Basic pulse duration is easily adjustable within a wide range to suit local conditions so that a motor-driven load can be accurately positioned. An electric motor of any type or characteristic, small or large (from fractional-hp. to 25 hp. and more) can be controlled. Follow-up action is a function of both extent and speed of knob rotation. Used in place of push buttons, "Type B Pulsing Drive" gives a non-skilled operator perfect control over a motor.—*Yardeny Laboratories, Inc., 105 Chambers Street, New York 7, N. Y.*

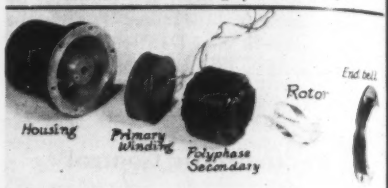
Please mention number 934 when filling out card

Dragless Pointer-position Transmitter

New "Synchrotel" is an electro-mechanical pick-off said to serve as a "virtually frictionless voltage control and synchronous transmitter." Although developed primarily for use in aircraft instrumentation, unit finds application in process industries. It is essentially an a-c. synchromotor type of electromagnetic pick-off device, which can be attached directly to pointer of a sensitive aircraft and other instrument without affecting accuracy of instrument. It converts reading into electrical signals which can be sent to a remote station with accuracies of a fraction of a degree of arc. Signals



"Synchrotel" mounted into true airspeed indicator between dial and body of mechanism



may be used in a servomechanism to direct an airplane, control engine temperature, operate a flight recorder or make airspeed adjustment in a bomb-sight. In like manner, in other industries it can serve both in transmitting and regulating pressure, temperature, flow-rate, etc. By incorporating a "Synchrotel" inside case of a conventional instrument, visible indication complements remote-control signal. See Fig. 1. Feature of new synchro is that the only moving part weighs 1/25th oz., may be mounted on tiny jeweled bearings, can be positioned by feeble torque produced by precision-instrument pointer. See Fig. 2. Low weight and consequent low inertia of rotor enhance usefulness of new synchro where high angular accelerations and oscillations are to be measured or controlled.—*Kollsman Instrument Div., Square D Co., 80-08 45th Ave., Elmhurst, N. Y.*

Please mention number 935 when filling out card

Dial Indicator

New "Micronar" quadrant type dial indicator has standard mounting dimensions, is claimed to "extend . . . field of accuracy which can be covered by a wholly mechanical dial indicator"; is suited for use on comparators and on fixtures for controlling especially close tolerances. Scale of English-unit model is divided into 0.0001" steps and in central portion these intervals have

been subdivided to 0.00002". Consistent repeatability and accuracy in keeping with these fine divisions is claimed. Effective range is 0.0018". Metric model is graduated in 0.001mm and has a range of 0.04mm. Dial is rotatable over a small angle by means of a fine adjusting screw to facilitate setting to a standard. "Micronar" is regularly furnished with a sapphire-tipped contact point.—*Standard Gage Co., Inc., Poughkeepsie, N. Y.*

Please mention number 936 when filling out card

Condensate Remover

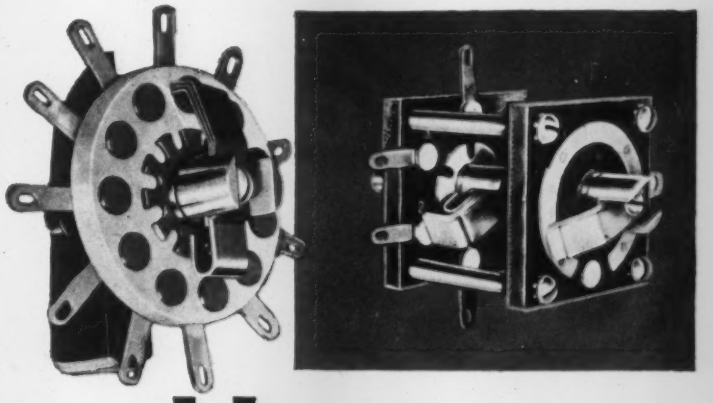
New "Drainator" for removing condensate from steam condensing devices, kettles, presses, etc., has no moving parts, utilizes thermodynamic properties of steam and hot water to regulate flow through device. Features include:

(1) positive visual indication at all times not only that condensate is flowing, but that all condensate is being eliminated; (2) means for handling entrained air, capacity increasing in proportion to amount of air present. Sizes from ½" to 1½", in a range wide enough to accommodate any drainage condition.—*Coe Mfg. Co., Painesville, Ohio.*

Please mention number 937 when filling out card

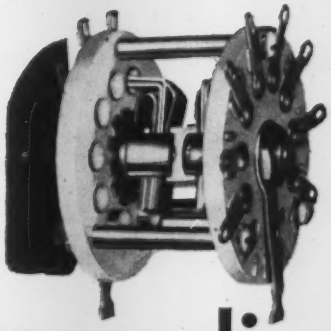
Higher-voltage Equipment for Oscillography

New equipment which takes full advantage of ultra-rapid writing rates and brilliant trace of "Type 5RP-A" multi-band tube, consists of two units: "Type 281 High-voltage Cathode-ray Indicator" and "Type 286 High-voltage Power Supply," available together or separately, usable in combination or as individual instruments. "Type 281" is a self-contained instrument featuring "Type 5RP-A" multiband cathode-ray tube operating at a total accelerating potential of either 4 or 8 kv. These self-supplied potentials are adequate for most oscillographic studios, but when "Type 286" is employed as an auxiliary supply, over-all accelerating potential applied to tube is 29 kv. and writing rates as high as 400" per microsecond can be recorded. A graduated scale with 1/10" divisions is permanently mounted on tube face. Capacitive and direct (conductive) connections are provided for both *X*- and *Y*-axes. Terminals for the application of *Z*-axis signals to either cathode or grid of the "5RP-A" are available on front panel. Input circuits will accommodate peak deflection voltages corresponding to twice full-screen deflection even when

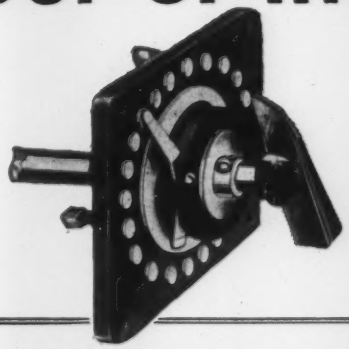


Shallcross

for



out-of-the-ordinary



Switches

AKRA-OHM PRECISION RESISTORS
14 Standard Types. 50 available special designs.

HIGH-VOLTAGE TEST EQUIPMENT
1.5 to 200 KV

BRIDGES
Wheatstone, Kelvin-Wheatstone, Percent Limit and Fault Location Types

DECADE BOXES
1 to 7 dial types, 0.1 to 11, 111, 110 ohms

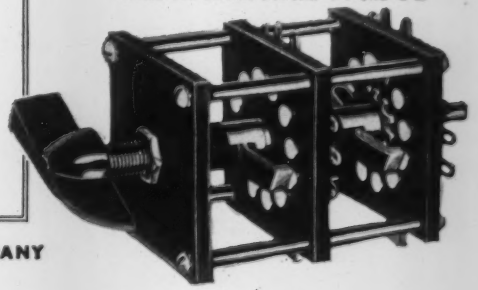
VOLTAGE DIVIDERS (DECADE POTENTIOMETERS)
Voltage ratios 0.0001 to 1.0

ATTENUATORS & CONTROLS FOR COMMUNICATION EQUIPMENT

LOW RESISTANCE TEST SETS
From 200 micro-ohms to 100 ohms

Shallcross Switches offer a broad assortment of finely made, low contact resistance rotary selector switch types for exacting applications. Numerous standard types in single and multi-section units up to 180 contacts can readily and economically be adapted to specific requirements.

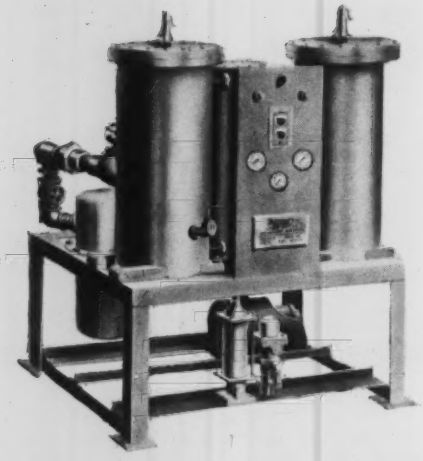
Write for Switch Bulletin C-1 and C-2



SHALLCROSS MANUFACTURING COMPANY
DEPT. IS-97, COLLINGDALE, PA.

INSTRUMENT AIR DRYERS for

Hazardous Areas



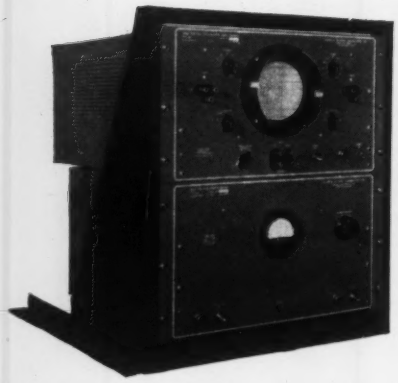
Dehydraire *Silica Gel units are now available for installations in hazardous areas in refineries and chemical plants. There are 6 low priced models—capable of drying the air for from 100 to 500 instrument installations—either semi or full automatic, single or polyphase; Class I Group D explosion-proof construction. Where 100 lb. or higher steam pressure is available, non-electric all steam semi-automatic units can be furnished.

*Davison Silica Gel.

Address our Sales Engineering Department for full information regarding Dehydraire units for your installation. Give us number of instruments installed — or contemplated; also pressure and temperature of your compressed air supply.

Dehydraire CORPORATION

14-13 118th St. College Point, N. Y.

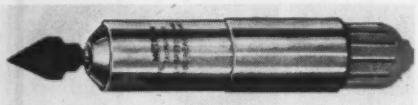


the unit is operated at 29 kv. Balanced potentials furnished for operation of positioning circuits are so regulated that line-voltage changes do not de-position spot. "Type 286 High-Voltage Power Supply," though designed as companion equipment, can also be used for other purposes. It provides a rectified r-f. high-voltage supply, and consists of an r-f. oscillator and associated power supply, a step-up transformer for the r-f. voltage, a voltage-double rectifier, a high-voltage filter, an output meter, and output-regulator circuits. D-c. output voltage is variable from +18 kv. to +25 kv. by means of a front panel control, and is measured. Output is regulated so that line-voltage variations or changes in external-load current requirements have little effect upon it. Supply is shielded to permit its use close to sensitive circuits or cathode-ray tubes.—*Allen B. DuMont Labs., Inc., Clifton, N. J.*

Please mention number 938 when filling out card

Tachometer Adapters

New high- and low-speed adapters for use with maker's hand tachometers increase or decrease speed-measuring ranges of these tachometers by a factor of 10. They are gear type speed changers which slip over standard tachometer head. With "Type 46A" adapter for low speeds (down to 10 rpm.), user merely drops a zero from scale reading to get actual speed; with "Type 46B" for high speeds (up to 100,000 rpm.), user adds a zero. Adapters have ball bearings and hardened steel gears; are designed to fit in standard carrying case along with the tachometer itself. — *Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.*



Please mention number 939 when filling out card

Distortion Meter

New "Model 400 Distortion Meter" for laboratory or field use has variable-frequency selective filter providing single frequency suppression circuit for frequency range of 50 to 15,000 cycles. Circuit consists essentially of a Wien bridge null balance included in a feedback amplifier in combination with sensitive VTVM and accurately-calibrated attenuator. Amplifier is capable of com-

What's YOUR special battery problem?

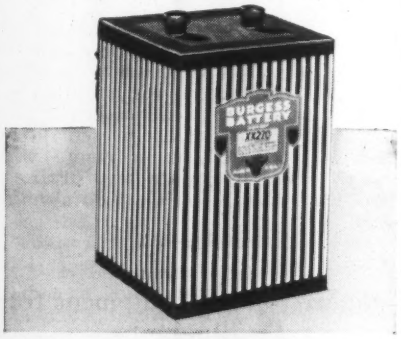
Here's another tough one Burgess engineers solved

THE PROBLEM

To build—to rigid physical specifications—a battery of 400 volts for a constantly intermittent drain 24 hours a day and to have a useful life of 1 year.

THE SOLUTION

A compact ruggedly constructed unit 3⅞" x 3⅞" x 6 1/16" equipped with insulated terminals and with an initial voltage of 400. Designed with the type of cells necessary to deliver this continuous service 24 hours per day for one year.



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Send for this free check-sheet . . . it enables you to easily and quickly provide Burgess engineers with all information important to design of a battery for your special requirements.

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Freeport Illinois

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HOW often have you been keenly interested in new products but failed to find out more because you had no time to write letters? Many times, no doubt, you regretted having let the matter slip your mind.

It will take you but two or three seconds to write each number on the card on page 869.

plete fundamental frequency suppression but produces no attenuation of frequencies removed one octave or more. It contains an integral power supply. Frequency range: (a) distortion meter for fundamentals from 50 to 15,000 cycles, measuring harmonics up to 45,000 cycles; (b) as voltmeter and d.b. meter, from 30 to 30,000 cycles. Sensitivity: (a) Noise and distortion measurements, minimum input 0.3 volts; (b) voltmeter, full-scale readings of 0.3, 0.1, 0.03, 0.01, and 0.003 volts. Indicator, 3" fan type scaled as follows: (a) distortion ranges 30 to 100%; 10 to 30%; 3 to 10%; and 0.5 to 3%; (b) noise ranges —10db; —20db; —30db; —40db; —50db and, by proper use, may be extended to —70db. Calibration: for distortion measurments ±10%; for noise measurements ±1db; for voltage measurements ±5%. Dimensions: 13¾" × 7¼" × 9½".— Weight: 11½ lbs.— *Barker & Williamson, Inc., 237 Fairfield Ave., Upper Darby, Penna.*

Please mention number 940 when filling out card

Instrument Soldering Iron

New "No. P-30" electric soldering iron, suitable for fine soldering of instruments, can be furnished with ⅛" or ¼" diam. tip and in 40, 50, or 60 watts. It works off 110- or 220-volt line

circuit, d.c. or a.c. any cycle. No transformer required. Iron is equipped with a 6-foot, 10,000-cycle approved heater cord and shatter-proof rubber plug. Heating elements are of best grade nickel-chromium resistance wire, insulated with finest grade mica. User can replace element with ease. Tips are hard drawn copper; simple to remove. Cool comfortable handle is also removable. Each iron is furnished with a stand.—*Hexacon Electric Co., 179 W. Clay Ave. Roselle Park, N. J.*

Please mention number 941 when filling out card

Film Defect Indicator

New Film Defect Indicator, for rapid and thorough mechanical inspection of 16mm. sound and silent film perforations, is said to fill a pressing need of film libraries, laboratories, and industrial film users. As film is wound through device, perforations are mechanically inspected and, when a broken or damaged perforation is encountered, a warning light calls the attention of the operator to the imperfection. Indicator may be removed from

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Men of science are constantly probing . . . ever seeking . . . always wondering . . . never satisfied.

Every fresh discovery reveals anew the vastness of that "Great Undiscovered Ocean of Truth," and presents countless new problems in MEASUREMENT.

To keep abreast with the ever-changing needs of modern research, Hathaway engineers are constantly working on new measuring instruments, constantly improving older ones. Whatever may be YOUR new problem in MEASUREMENT OR CONTROL, Hathaway experience can help you.

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- For general-purpose laboratory and field use
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Write for Technical Bulletin SP-165 B

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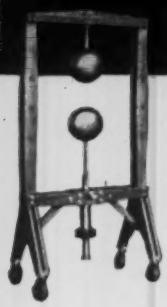
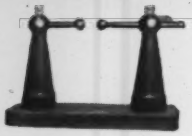
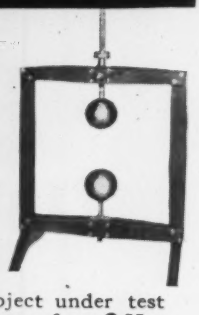
FOR HIGHEST ACCURACY
in your high-voltage measurements--
Use SPHERE GAPS







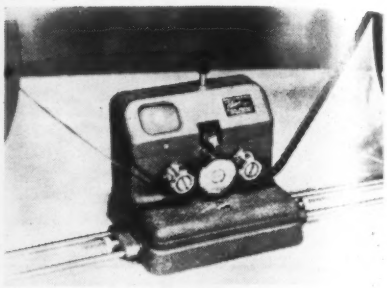
G.E. OFFERS a complete line for a-c and d-c testing

Advantages: ● No overvoltage on object under test ● Crest voltage indicated regardless of wave form ● Not appreciably affected by humidity ● Practically no time lag ● Spark-over voltages consistent.

Available in seven sphere sizes, 2 to 100 centimeters in diameter, for spark-over voltage ranges of 8.5- to 45-kv crest up to 261- to 1338-kv crest. Current-limiting resistance assemblies are included. If desired, a motor drive can be obtained on the larger sphere gaps for easy adjustment. Write for Bulletin GEA-4559. *Apparatus Dept., General Electric, Schenectady, N. Y.*

401-79

GENERAL ELECTRIC



its base and mounted on a B&H "Filmotion Viewer" base, thus combining indicator and splicer for rapid inspection and repair. Indicator is fitted to take standard B&H connecting rods, may be used between B&H Heavy Duty Rewinds, or set up in series to become part of complete B&H Filmotion Editor.—*Bell & Howell Co., 7100 McCormick Rd., Chicago 45, Ill.*

Please mention number 942 when filling out card

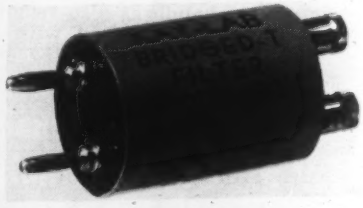
Photoelectric Counter or Inspector

New "Shadowmaster" consists of a light-source unit and a photo-amplifier unit, both designed for severe industrial service: moisture, dust, etc. Units may be as far apart as 75 feet. New system differs from maker's "Shadowcount" in this high sensitivity and also in that plate circuit relay is energized as long as object interrupts light beam; focal point can be set to such a small diameter that objects as small as 1/32" in cross-section can be counted or, in some cases, inspected. Safety relays can be supplied to actuate alarm or shut off equipment in event of burn-out.—*The Autotron Co., Danville, Illinois.*

Please mention number 943 when filling out card

Hum Filter for Instruments

New "Kay-Lab Bridged-T Hum Filter" completely cancels 60 cycles, is designed for high-impedance instruments such as oscillographs. By inserting filter at input terminals, stray hum

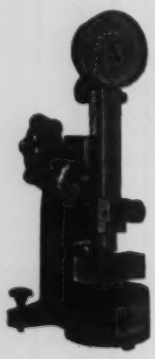


pick-up is eliminated, even though open leads are used. Matching transformers are unnecessary and there is a common ground from input to output. "Bridged-T" laboratory filters are also available at 120 cycles and other frequencies. Dimensions: 1½" diameter, 2" long, excluding terminals.—*Kalbfell Laboratories, Inc. 1706 Morena Blvd., San Diego 10, Calif.*

Please mention number 944 when filling out card

HARDNESS TESTING...

done WITH NO METAL HAZARDS. The SCLEROSCOPE has done it for the past 40 years.



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- 6" HIGH VISIBILITY DIAL
- 0-50 INCHES OF WATER UP TO 0-200 P.S.I.
- UNIVERSAL MOUNTING
- RUPTURE-PROOF BELLOWS UNIT

Write for Bulletin 181-1

BARTON INSTRUMENT COMPANY
3500 UNION PACIFIC AVE.
LOS ANGELES 23, CALIF.

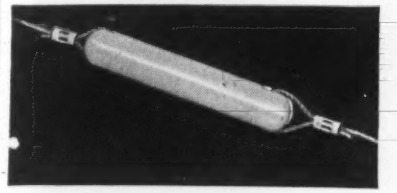
Instrument-room Blower

New "Bantam B-2 Blower," for ventilating and cooling instruments, electronic tubes, projectors, etc., delivers 2 CFM. 110-volt 60-cycle a-c.d-c. unit is 3⅛" × 3½" × 3¾". Prompt deliveries. —*Small Motors, Inc., 2076 Elston Ave., Chicago, Ill.*

Please mention number 945 when filling out card

Small-wire and Cable Connector

New "Solistrand" solderless wire connector provides a quick, efficient method of mechanically fastening solid or

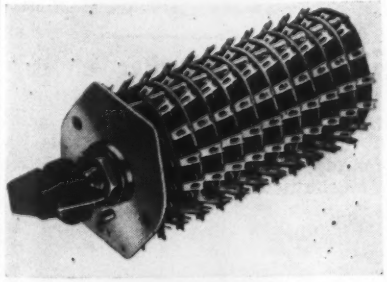


stranded wires and cables of small diameter. Two types are available: Parallel Connector and the Ring Tongue Connector. Both eye splices and straight splices can be made with the Parallel Connector (typical use illustrated: installation of insulators). Flat "tongue" or tab of Ring Tongue Connector has an accurately-sized stud hole. —*Aircraft-Marine Products, Inc. 1568 North 4th Street, Harrisburg, Pa.*

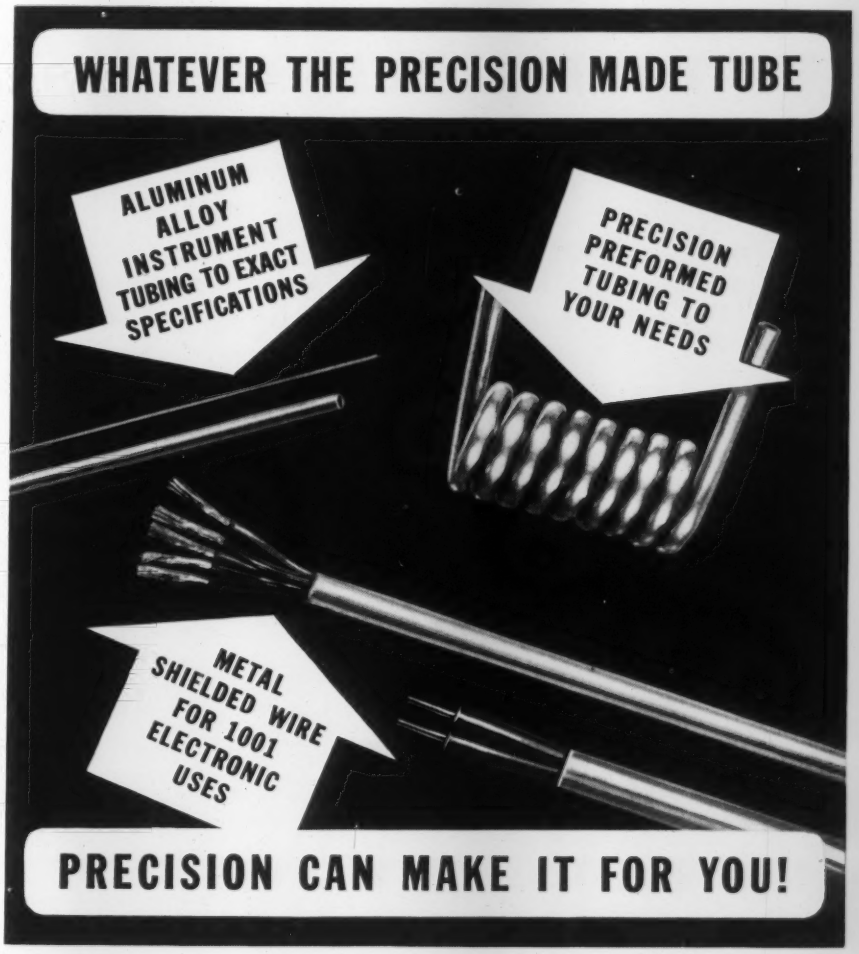
Please mention number 946 when filling out card

Rotary Selector Switch

New rotary selector switches are available in up to 32 positions with 10 decks. All switches are rated at 5 amp. at 120 volts, make and break. They are



made in shorting and non-shorting types with or without water-tight shaft construction and are suitable for low or high current and low or high impedance circuits. Breakdown voltage between terminals or between terminals and ground is over 2500 volts. Dual contacts between terminals and connector ring


WHATEVER THE PRECISION MADE TUBE
ALUMINUM ALLOY INSTRUMENT TUBING TO EXACT SPECIFICATIONS
PRECISION PREFORMED TUBING TO YOUR NEEDS
METAL SHIELDED WIRE FOR 1001 ELECTRONIC USES
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You name your needs in accurately drawn seamless brass, copper, nickel, aluminum or other non-ferrous metal tubing and we have your answer. Every inch of Precision-made tubing is produced to exact requirements made possible by our special annealing process. Tubing with outside diameters ranging from 0.375″ to 0.010″ with a wide range of wall thicknesses.

POINTER TUBING to the most exacting specifications and also formed to your own particular needs. Made of various aluminum alloys in any wall thickness down to one and one-half thousandths (0.0015″)

PREFORMED TUBING held to extremely close tolerances as specified by your engineering figures.

METAL SHIELDED WIRE, a new and different product performance-proved for its superiority. Consists of an inner conductor, dielectric and seamless metal tube, forming a coaxial pair of conductors. Shield and conductor remain coaxial even when formed into intricate shapes.

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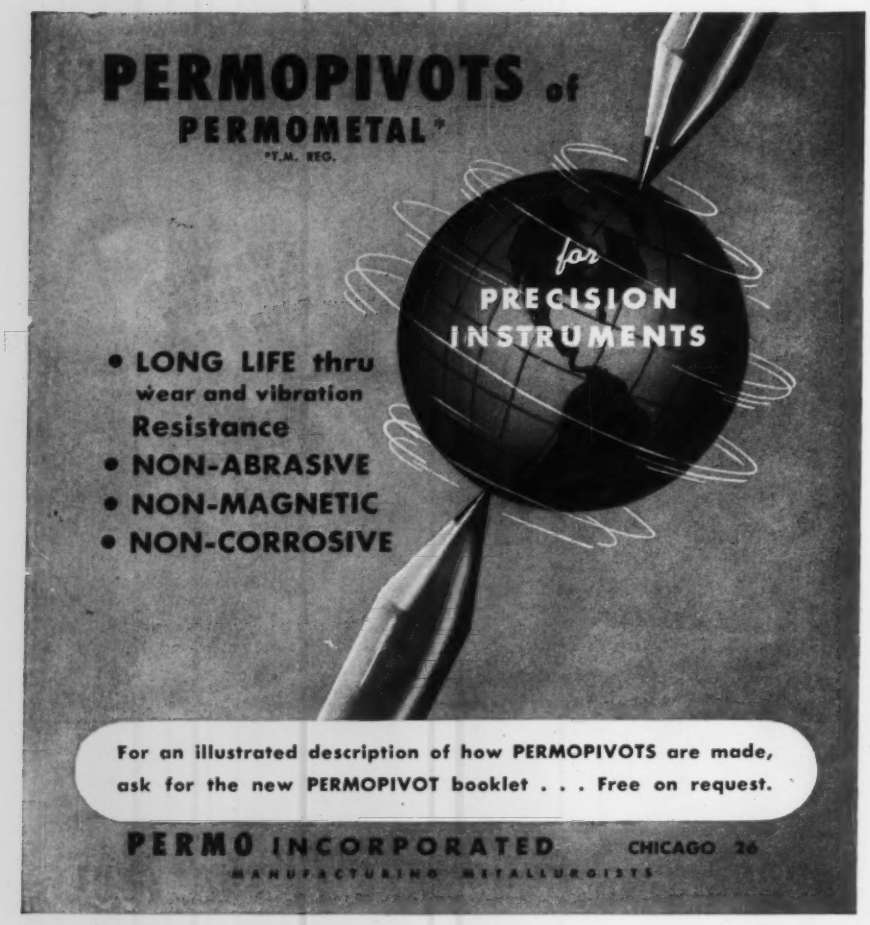
BRANCHES IN ALL PRINCIPAL CITIES



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PARABOLIC or SPHERICAL Mirrors.

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Type 5012 Accuracy ½ of 1% DC
Size 12"x 8"x 6"

A Combination AC Multimeter and DC Multimeter

Range of Measurements

DC 1 Microampere to 1 Ampere.
20 Microvolts to 1000 Volts.

AC (thermocouple type)
2 Milliamperes to 3 Amperes.
60 Millivolts to 1000 Volts.

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WE ALSO SUPPLY
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THERMOCOUPLE AC METERS
MULTIMETERS
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Special apparatus built to order

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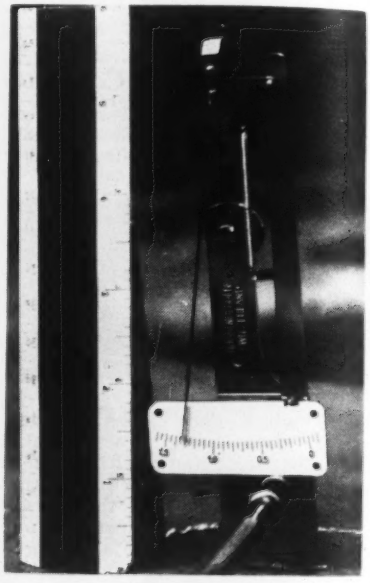
are obtained by use of inde[pen]dent parallel circuits. Maximum tra[ns]fer of power is attained by 0.004" thic[k]ness of rolled-on silver at contact su[r]face—a thickness said to be much grea[ter] than that usually found on plated c[on]tacts. Contact resistance is less than [one] milli-ohm. Each switch deck is a s[el]f-contained self-aligning assembly, ea[si]ly removed and replaced. Single-hole mount[in]g on panels up to ⅛" is pro[vi]ded on standard switches.—*United States Instrument Corp., 409 Broad St., Summit, N. J.*

Please mention number 947 when filling out card

Tensometers

New supply is announced for "Hug[en]berger Tensometers" which had be[co]me unavailable early in the war after imports from Switzerland ceased. Sev[en]



eral types are available. One is a laboratory instrument of "high accuracy and great sensitivity." Two others, more sturdy, are suitable for use in adverse climate, dusty shops and buildings. Another is exceptionally light in weight. A fifth, also light in weight, is for studying celluloid models and in field-of-force investigations. All depend on accurate level multiplication of strains.—*Baldwin Locomotive Works, Philadelphia 24, Penna.*

Please mention number 948 when filling out card

VFO Exciter

New "Model 500 VFO Exciter" is both a low-powered transmitter and a "de luxe exciter" for the amateur who demands an exceptionally high degree of mechanical and thermal stability." Each unit is temperature cycled for drift compensation and is supplied with a calibration chart for definite frequency reference. Absolute frequency retrace may be obtained by beating the 5th harmonic of the 2 Mc. fundamental against WWV on 10 Mc. Output coupling reactance on the VFO is eliminated. Grounding output or coupling a tuned circuit to exciter will cause a frequency shift of less than one part in 8,000,000. Oscillator stability is virtually unaffected by changes in line

For Your Greater Convenience

HOW often have you been keenly interested in new products but failed to find out more because you had no time to write letters? Many times, no doubt, you regretted having let the matter slip your mind.

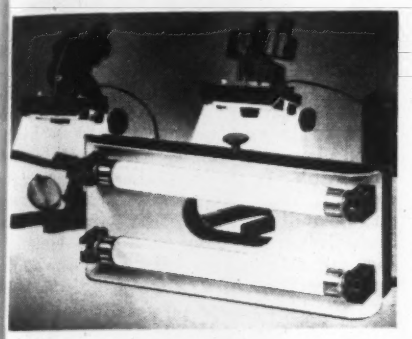
It will take you but two or three seconds to write each number on the card on page 869.

voltage of as much as ±25%. For those who do not require complete unit, "Model 502 VFO" complete with dial assembly and full instructions may be obtained separately. VFO is capable of driving a 6L6 or similar tube to normal output as a straight amplifier or doubler.—*Barker & Williamson, Inc., 237 Fairfield Ave., Upper Darby, Pa.*

Please mention number 949 when filling out card

Miniature Fluorescent Microscope Lamp

New cool light source of high intensity and uniform field is for direct attachment to most types of microscopes.



Twin 4-watt fluorescent lamps straddle microscope objective lenses. Halos and highlights are eliminated by length and separation of bulbs and by nature of fluorescent light itself. Light intensity is 450 foot-candles at 3" working distance and a color temperature of 3500°K. Bulb life of 2500 hours may be expected; replacement bulbs are available at all electrical supply sources. Lamp operates on 115-volt 60-cycle a.c. Dimensions: 1⅜" high, 2¾" wide, and 6¼" long. Several styles of attaching brackets are available.—*Stocker & Yale, Marblehead, Mass.*

Please mention number 950 when filling out card

"Wow-meter" or Speed-variation Indicator

New "Model 115 Wow-Meter" is a direct-indicating instrument for measuring variations and fluctuations of the

CURRENTLY

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Manufacturers of
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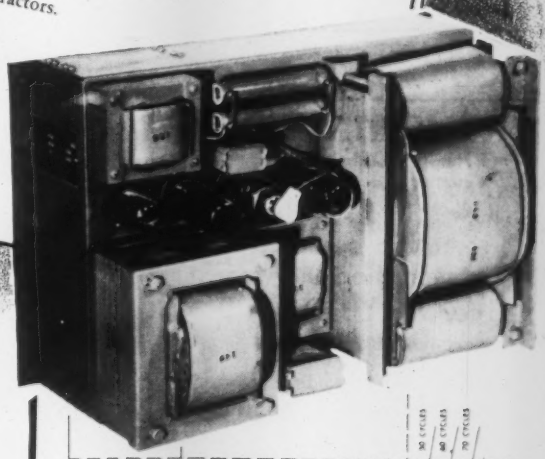
RUNAWAY VOLTAGES STOPPED AT 1/10 OF 1%

Rated performance of Model 1750-S *guarantees* delivery of output line voltages at a regulation accuracy of 0.2% under varying load. However, in *actual tests* of this unit voltage stabilization was held to within 0.1% under full operating conditions. This conservative safety rating of 0.2% is typical of all Sorensen performance factors.

Input voltage range	95-125
Adjustable output between	110-120
Load range	200-2000 VA
Regulation accuracy	0.2%
Harmonic distortion	2% max.
Recovery time	6 cycles
Input frequency range	55-65 cycles



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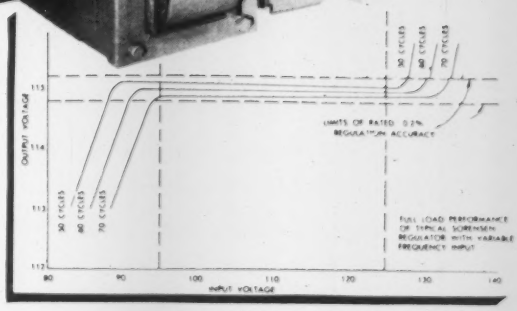

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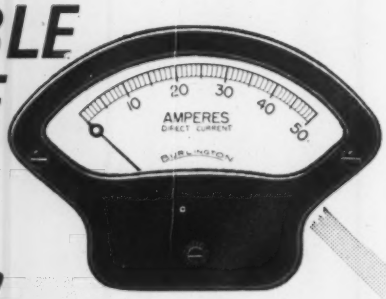

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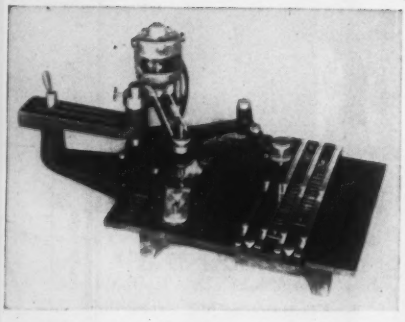

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Attachments adapt it to small or large work on flat or curved surfaces.

Excellent engraving can be produced by an inexperienced operator.

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speed of phonograph turntable and other mechanical, optical and magnetic recording and reproducing equipment. These variations, commonly called "wow," actually represents a frequency modulation of the original signal, with modulating frequencies usually extremely low. Instrument requires use of a 1000-cycle phonograph record for testing phonograph turntables and equivalent signal sources for other recording and reproducing equipment. It comprises a frequency meter; output of frequency-meter circuit consists of a steady voltage or component proportional to average or unmodulated frequency of input signal and varying components proportional to frequency deviations and fluctuations. A filter circuit separates steady component from varying components. These are amplified by a stabilized amplifier of known amplification whose output is then measured by a peak-to-peak-reading VTVM circuit previously calibrated by a known portion of steady-component frequency-meter output. Thus VTVM can be calibrated for these frequency variations in terms of percent of steady component: variations of frequency are expressed in percent of average frequency of input signal. Provisions are made for connection of a low-frequency wave-analyzer (e.g., General Radio Co. Vibration Analyzer) to determine presence of particular "wow" frequencies. In "Model 115-R" an additional stage of amplification is provided to permit connection of a high-speed, low-impedance, direct-inking oscillograph (e.g., Brush magnetic recorder). This model can also measure non-periodic frequency fluctuations. Sensitivity (of both models): Depending on setting of range switch full-scale readings of 3% wow and 1% wow may be obtained on an essentially linear scale. Accuracy, 5% of full-scale value. Output to recorder ("Model 115-R") up to approx. 25 volts, rms., depending on gain setting, from 750-ohm source impedance. — *Furst Electronics, 800 W. North Ave., Chicago 22, Ill.*

Please mention number 951 when filling out card

Ohmmeter

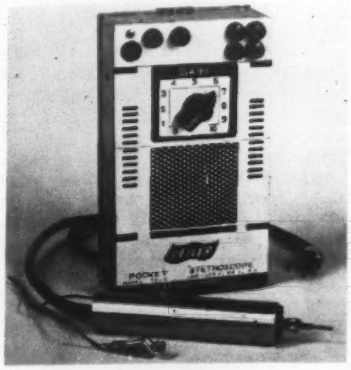
New "Model 246 Precision Ohmmeter" is ruggedly built, is easy to handle and is said to insure "extraordinary accuracy" through use of

precision wire wound resistors, individual calibration, unusually long (4½") hand-stepped scale, superior workmanship by specialists in the field of instrumentation. Two #6 dry cells provide ample power supply with long life. Over-all dimensions 7¾" × 6" × 7 13/16". "Model 246" checks resistors as low as one ohm and up to 100,000 ohms on four overlapping scales of 0-100, 0-1000, 0-10,000 and 0-100,000 ohms.—*Associated Research Inc., 231 S. Green St., Chicago 7, Ill.*

Please mention number 952 when filling out card

Signal Tracer

New "Model TS-5 Pocket Stethoscope" signal tracer operates on 115 volts a.c., will trace a signal through a radio or other electronic device by



touching its probe to key points of circuit, same as bench-type Models "TS-2" and "TS-3"; but has advantage of being small and light. Size: 4⅛" wide, 2⅜" deep and 8¾" high; weight 3½ lbs. complete. "Stethoscopes" contain their own PM dynamic speakers but provisions are also made for headphone operation. Any standard type volt-ohm-milliameter may be plugged into convenient jacks to make an effective r-f. VTVM.—*Feiler Engineering Co., 422 S. Dearborn St., Chicago 5, Ill.*

Please mention number 953 when filling out card

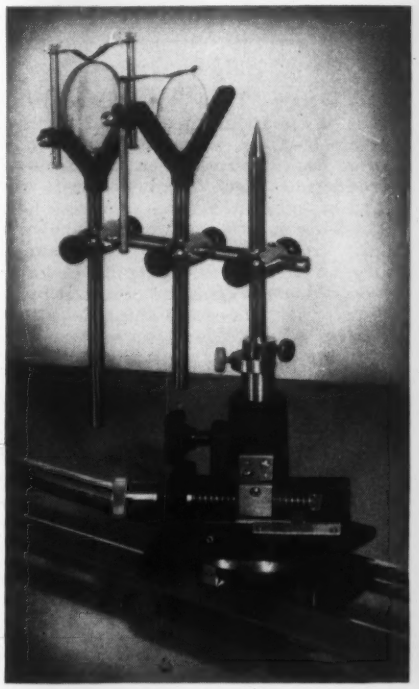
Vacuum-tube Volt-ohmmeter

New "Model 110 Television Type Vacuum-tube Volt-ohmmeter said to be ideal for servicing industrial appliances reads to 15,000 volts d.c., with d-c.

Gaertner

OPTICAL BENCHES

AND ACCESSORIES



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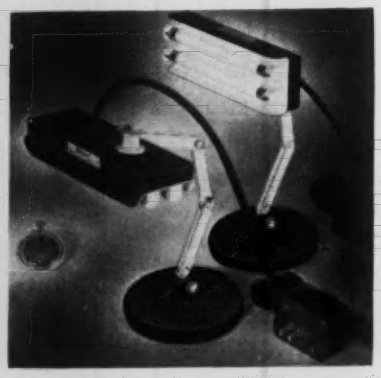
ranges 3-30-150-300-600-3000-15,000 volts; a-c. ranges 3-30-150-300 volts good to 300 megacycles; ohms: 1000-10M-100M-1 meg-100 meg. Construction includes heat loop on all critical resistors; also fungus proofing to maintain stability and accuracy over a long period of time. High d-c. voltage readings and high-frequency a-c. readings that are necessary in servicing television receivers are available in this instrument. —*Electronic Mfg. Co., 140 South Second St., Harrisburg, Penna.*

Please mention number 954 when filling out card

Miniature Fluorescent Light

New miniature fluorescent lamp is suitable for instrument work. Design produces a light intensity of 550 foot-

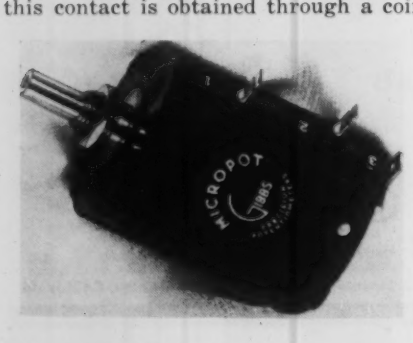


candles at a 3″ working distance and a color temperature of 3500°K. Normal operating temperature of 115°F. allows close work without objection of radiant heat and hot surfaces. Lamp operates on 115-volt 60-cycle a.c. Twin 4-watt bulbs of standard manufacture are rated at 2500 hours normal life and may be obtained at any electrical supply source.—*Stocker & Yale, Marblehead, Mass.*

Please mention number 955 when filling out card

Precision Voltage-dividing Resistor

New "Micropot" is a new type of precision, ten-turn helical voltage-dividing resistor. It is linear within 0.1% (resistance is directly proportional to shaft rotation over entire range of a 20,000-ohm unit to within ±20 ohms). Ten full turns on standard ¼″ shaft drives a sliding contact across more than 40″ of wire-wound resistance element. Complete unit is 2⅛″ in diameter and extends but 2⅛″ behind panel. Precious-metal sliding contact is carried on a nut operating along a ground-thread, stainless steel lead screw. Connection to this contact is obtained through a coin



silver disk and two precious-metal contacts. Running torque is said to be less than 1.5 in-oz. at room temperature and not greater than 3 in-oz. between −55° and +70°C. "Micropots" are available in several resistance values from 1,000 to 30,000 ohms. Special sizes to order. —*Gibbs Div. of George W. Borg Corp., Delavan, Wis.*

Please mention number 956 when filling out card

Automatic Inspectors for Ball Bearings

(1) New "Type WAA Race Tester" (Fig. 1) is a shop instrument for measuring surface waviness of inner and outer ball and roller bearing races on a production basis. It gives direct readings of microinch r.m.s. average height of waves in two wave bands, shows visually number and shape of waves on any given race, and permits deviations from normal run to be detected by ear. Thus it permits establishing definite numerical specifications for waviness; and checking against specifications by direct

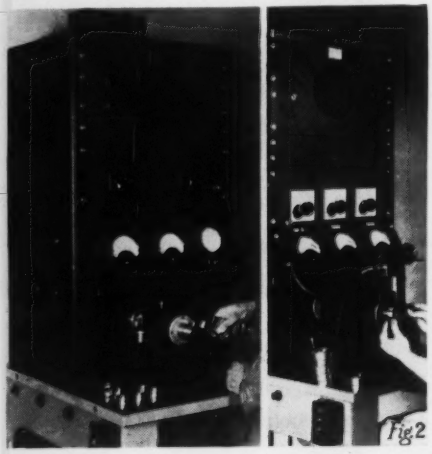


Fig 2

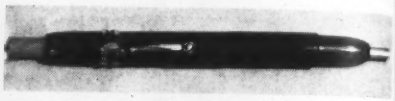
readings. "Race Tester" includes following units: (1) a motor-driven high-precision spindle; (2) a manually-held electromagnetic converter; (3) a four-channel amplifier unit; and (4) the indicating devices, consisting of two microinch meters, an oscilloscope and a loudspeaker. Inner races are mounted on a plug adaptor in the spindle, while outer races are held in a cup adaptor. To operate, inspector puts proper adaptor in spindle, slips race onto adaptor, holds felt tip of converter against the rotating surface and makes required observations. Races can be tested in a fraction of a minute, including size change.

(2) New "Type BAA Anderometer" (Fig. 2) is a high-speed shop instrument for obtaining an over-all quality rating of assembled ball bearings. It is simple to operate, and permits testing several thousand bearings daily. It is calibrated in terms of height in microinches and frequency of occurrence of radial movements of outer bearing race as inner race rotates. Thus it puts factor of bearing quality on a quanitative basis. It permits purchasers to write definite numerical specifications for bearing quality, and to check complete lot of bearings quickly upon receipt. "Type BAA Anderometer" includes following units: (1) an interchangeable motor-driven cartridge-type spindle unit, clamped in a spindle housing; (2) an electromagnetic converter, mounted vertically on a slide in spindle housing and adjustable vertically for different bearing diameters; (3) a four-channel amplifier unit; and (4) three indicators and a loudspeaker. "Anderometer" can be used to test all ball bearings from 10 mm. to 60 mm. bore diameter. Over-all dimensions, 27″ wide × 33″ deep × 82″ high (including floor stand); net weight approx. 500 lbs. Power requirements are ¼ h.p, 220/440 volts, 3 phase, 60 cycles. —*Physicists Research Co., 321 S. Main St., Ann Arbor, Mich.*

Please mention number 957 when filling out card

Magnetic Probe

New "Magicbar" magnetic probe is said to be adapted to industrial, first-aid and household uses. It comprises

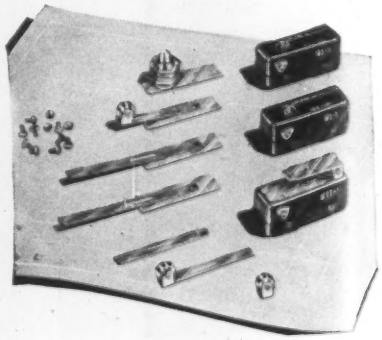


a streamlined plastic housing containing a powerful magnet which can be expelled from and retracted into housing (much like a mechanical pencil). A pocket clip is provided. What is said to be an exclusive feature permits automatic adjustment of effective strength of magnetic field. Magnet can be expelled from housing by turning a knob and strength of the magnet is a function of extent to which magnet is expelled: maximal when magnet is fully extended and minimal when magnet is fully retracted. Instrument Department uses include removal of magnetic particles from operating area of electrical instruments, etc.; to test coated surfaces to determine whether underlying material is magnetic; to remove sharp iron objects from storage bins; to retrieve magnetic items from sweepings, holes, etc. Plant First Aid Stations will use device for removal of steel splinters from eyes and skin. Adjustable magnetic strength feature makes it possible for nurse or doctor properly to orient splinter for extraction without painful rupture of tissues. Available in pairs comprising Blue Top (normal strength) and Red Top (super strength), also separately. —*Eljay Enterprises, P. O. Box 891, Newark 1, N. J.*

Please mention number 958 when filling out card

Switch Kit

New "Unimax Design Kit" for designers and model makers comprises a number of precision snap-action switches and an assortment of "Adapta-



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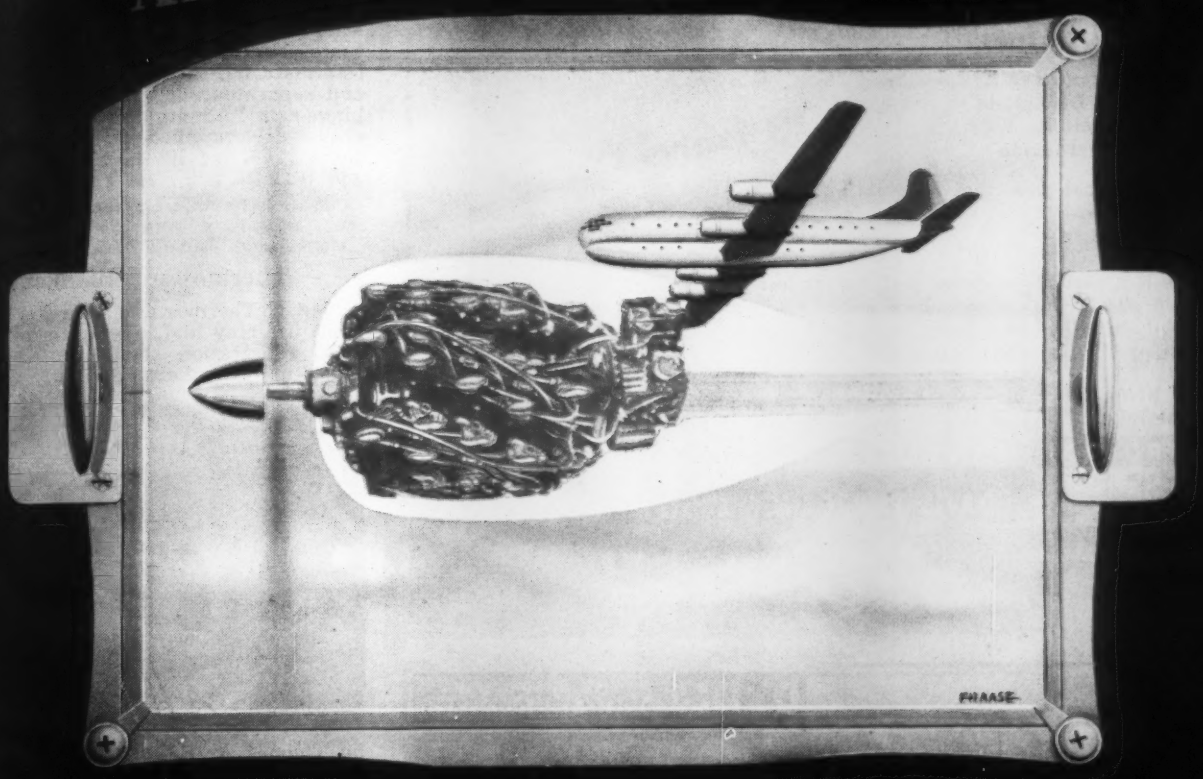

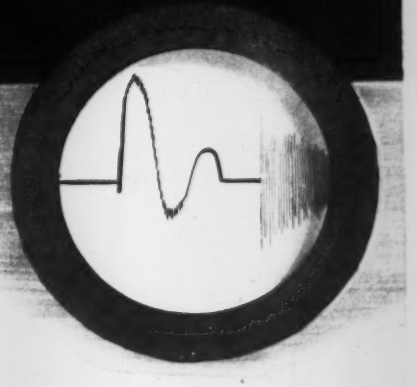

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■ The new Sperry Engine Analyzer will enable your flight engineer to keep his *eye on the pulse* of his engines—promptly visualize the slightest irregularity in engine function. In the analyzer indicator the flight engineer can examine at any time during flight, patterns that show the characteristics of engine vibration, ignition system performance, and synchronization between magnetos and between engines. These characteristic patterns *detect, locate* and *identify* the malfunctions and impending failures that may occur during flight operation.

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Instrumentation News

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The NEW DAVIS MICRO-GAS ANALYZER readily determines and analyzes the concentrations of these toxic gases or Vapors within their toxic range.

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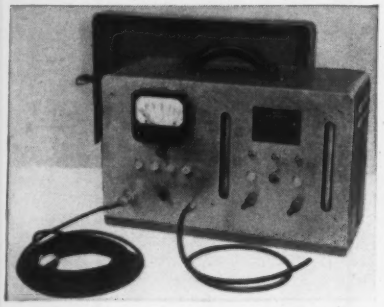
and any other gases that will ionize in water, with or without heat decomposition.



Here is a portable analyzer that weighs less than 35 pounds. Operates from a 110 AC Current. Continuous meter readings or when equipped with a record, furnishes permanent records of concentrations in P.P.M. (parts per million) of the gas being analyzed.

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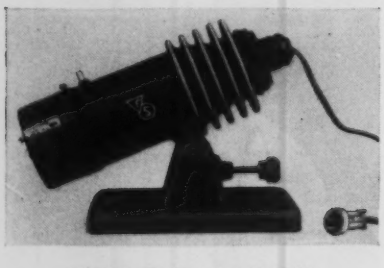

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Unique construction enables operator to rapidly determine temperature even on minute spots, fast moving objects, or smallest stream; no correction charts, no accessories, no maintenance expense. Special "FOUNDRY TYPE" and "Universal TRIPLE RANGE" have, in addition to standard calibrated range, a red correction scale determining TRUE SPOUT and POURING TEMPERATURES of molten iron and steel when measured in the open.

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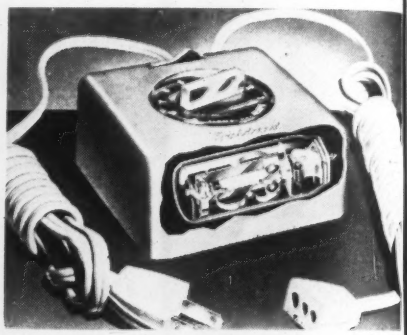
For further information use card on Page 869.

plates" whereby basic switches may be quickly adapted to varied means of applying actuating force. "Adaptaplates" include spring-plunger over-travel device for single-hole panel mount, plain leaf, leaf-and-roller, and hinge-arm actuator styles. Also furnished are plain leaf material, leaf-and-roller assembly, and separate roller for attachment to hinge-arm "Adaptaplate." Screws and rivets are supplied.—*Unimax Switch Corp. (subs. of W. L. Maxson Corp.), 460 W. 34th St., New York 1, N. Y.*

Please mention number 960 when filling out card

Thermostatic Blanket

New "Thermostatic Blanket" for home use may find laboratory or plant uses. Illustration shows control with sealed-in-glass thermal relay produced

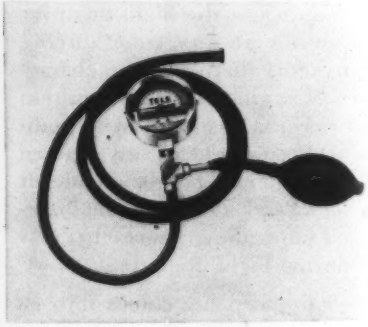


by Thomas A. Edison Inc. Instrument Div. exclusively for undersigned vendors. Advantages claimed for this thermal relay are: protection of contacts and other working parts from lint, dust, and corrosion; minimizing of contact fouling, pitting, and transfer because of an arc-quenching atmosphere within glass envelope; quietness of operation; great sensitivity, etc.—*Fieldcrest Mills Div., Marshall Field & Co., Inc., Chicago, Ill.*

Please mention number 961 when filling out card

Cooling-system-leak Detector

New "Tels" quickly and positively reveals leaks in cooling system of any internal combustion engine; thus prevents overheating and loss of antifreeze, reduces maintenance time and

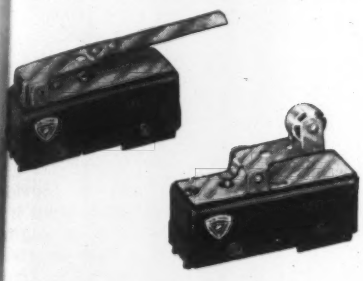


cost, cuts out-of-service time. It duplicates normal engine operating pressure at which most leaks become serious. (In most cases, these leaks cannot be detected when the engine is idling or shut down.) By applying proper test pressure (shown on complete chart supplied) maintenance man determines location of leak. Or, if there is no leak, he can quickly spot cause of overheating. "Tels" can be used on any type of liquid-cooled engine: gasoline or diesel, stationary or mobile, car, truck or tractor.—*James Industries, Inc., 215 Municipal Bldg., Skaneateles, N. Y.*

Please mention number 962 when filling out card

Hinged-arm Actuators for Precision Switches

New direct-acting and reverse-acting hinged-arm auxiliary actuators for maker's precision switches give special

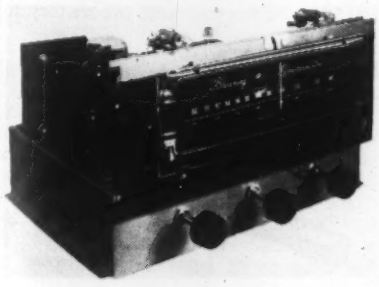


performance characteristics. Direct-acting hinged-arm "Adaptaplate" is designed to meet requirements for low operating force; reverse-acting type provides long over-travel with flat force gradient independent of switch characteristics and permits full over-travel with no over-pressure on basic switch. Hinged-arm "Adaptaplates" are removable and interchangeable among special types of basic "Unimax" switch, without altering operating characteristics of basic switch. Hinged-arm "Adaptaplates" require special length operating buttons, are not interchangeable with primary types.—*Unimax Switch Corp. (subsidiary of The W. L. Maxson Corp.), 460 W. 34th St., New York 1, N. Y.*

Please mention number 963 when filling out card

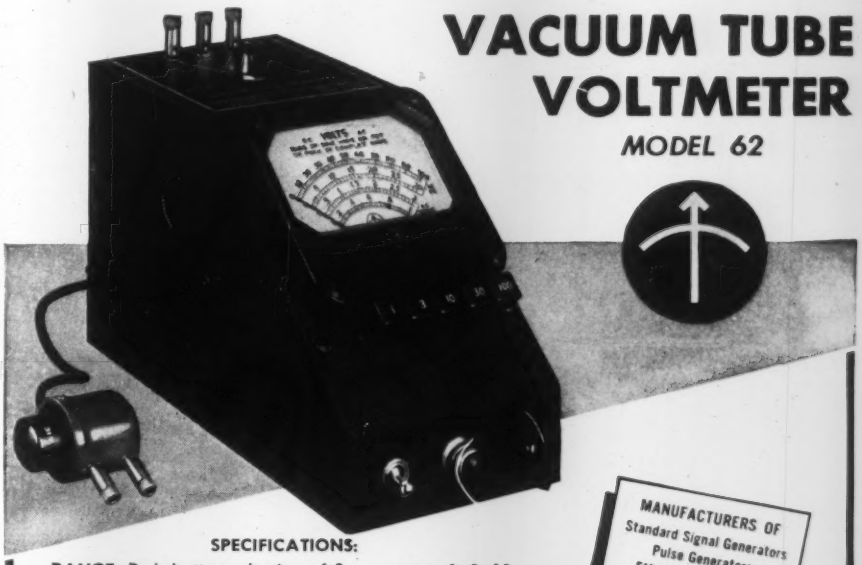
FM Tuner

New "Model RV-10" FM Tuner covers 88 to 108-Mc. band. Armstrong circuit with dual limiters provides exceptional freedom from noise. Sensitivity 10 microvolts. Antenna input designed for 300-ohm RMA standard downlead. Built-in power supply. Slide-rule dial with vernier drive has edge-lighted



VACUUM TUBE VOLTMETER

MODEL 62



SPECIFICATIONS:

RANGE: Push button selection of five ranges—1, 3, 10, 30 and 100 volts a.c. or d.c.

ACCURACY: 2% of full scale. Useable from 50 cycles to 150 megacycles.

INDICATION: Linear for d.c. and calibrated to indicate r.m.s. values of a sine-wave or 71% of the peak value of a complex wave on a.c.

POWER SUPPLY: 115 volts, 40-60 cycles—no batteries.

DIMENSIONS: 4¾" wide, 6" high, and 8½" deep.

WEIGHT: Approximately six pounds. *Immediate Delivery*

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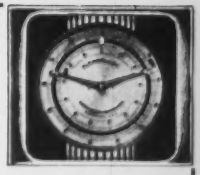
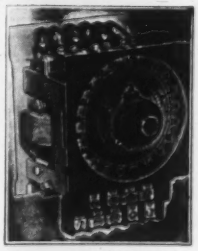
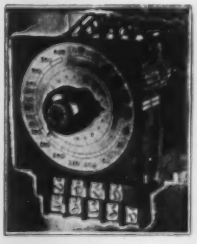
REPEAT CYCLE
Use where ON-OFF operation is continuously repeated. The ON time and OFF time are each adjustable on the dial. (FLEXOPULSE)



COUNTER
Use for limiting a process to an exact number of operations. The counter contact opens after 1 to 400 electrical impulses as selected on dial. Automatic spring reset. (MICROFLEX COUNTER)



MICROMETER DIAL
Provides exceptional timing accuracy where a circuit is to close or open with a time delay. Timing adjustable over wide range. (MICROFLEX TIMER)



MULTIPLE CIRCUIT —ADJUSTABLE
Use where several circuits are to close in a predetermined sequence. Time of closing and opening each circuit is adjustable. (MULTIFLEX TIMER)

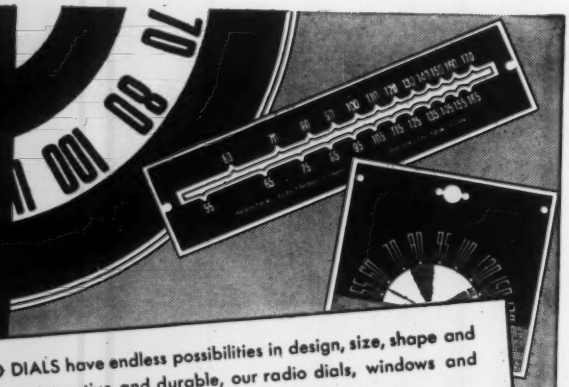
To reduce costs and improve quality of your products by automatic TIME-COUNT control . . .

★ Write for catalogue Bul. 291
★ Send for details of your control problems to Eagle for recomendations.
★ Consult Eagle representative in principal cities.

EAGLE Signal CORP

EAGLE Signal Corp.
MOLINE ILLINOIS

HOPP
Plastic
RADIO DIALS



DIAL WINDOWS
•
NAME PLATES
•
SCALES
•
GAUGES
•
CHARTS
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CALCULATORS
ETC.

PLASTIC RADIO DIALS have endless possibilities in design, size, shape and color combination. Attractive and durable, our radio dials, windows and scales are preferred by many leading Radio manufacturers.

Not only for dials, but for numerous other electronic and electrical applications, Laminated Plastics are preferable.

Consult with our artists and engineers regarding applications for your particular purpose. Or . . send blueprints or samples for quotation.

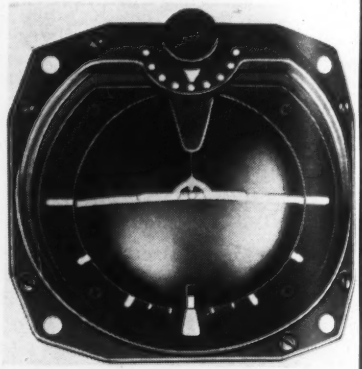
THE HOPP PRESS, INC.
ESTABLISHED 1893
460 WEST 34th STREET, NEW YORK 1, N. Y.

scale on which frequencies a[re] chan[ged] numbers appear. A tuning i[ndi]cator, incorporated in dial assemb[ly]. Dime[n]sions 6½" × 9" × 11". Weigh[s] 10½ l[bs]. (Also "Model RV-11 with sta[n]dard ra[dio] panel. — *Browning Laborato[ries, Inc.], Winchester, Mass.*

Please mention number 964 when filli[ng] out card.

Gyro-horizon

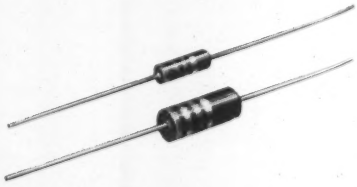
New "H-3 Gyro-horizon" (alrea[dy] selected by several airlines as standa[rd] equipment on Douglas DC-6) is an el[ec]tric-driven instrument which provid[es] unlimited indications in bank since it i[s] non-tumbling and requires no cagin[g]. Horizon bar indicates climbs or glid[es] to ±27°.—*Sperry Gyroscope Co., Gre[at] Neck, N. Y.*



Please mention number 965 when filling out card.

5%-tolerance Resistors

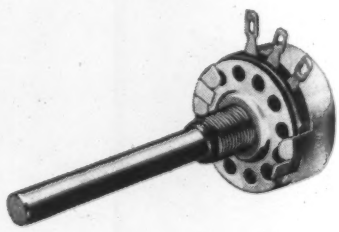
New ½ and 1-watt sizes with a tole[r]ance of ± 5% are announced in line o[f] "Little Devil" composition resistors, i[n] addition to standard line of 10% units. New resistors are available onl[y] through maker's distributors. Half-watt unit is ⅜" long and 9/64" diame[ter]; 1-watt unit is 9/16" long and 7/32" diameter. They meet all test re[-]quirements of JAN-R-11, including sal[t] water immersion cycling and high hu[-]midity tests.—*Ohmite Mfg. Co., 498[0] West Flournoy St., Chicago 44, Illinois*



Please mention number 966 when filling out card.

2-watt Voltage-dividing Resistor

New "Type AB Potentiometer" is a 2-watt molded-composition voltage di[-]vider for industrial and laboratory use



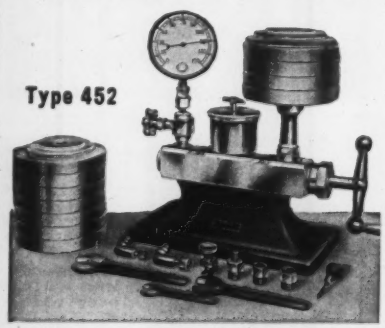
VITREOUS ENAMELED ROUND RHEOSTATS NEW SPRING-HINGED CONTACT ARM WRITE FOR CATALOG

TUBULAR RHEOSTATS & RESISTORS

ROUND RHEOSTATS
7 SIZES: From 50 to 500 WATT
SPRING-HINGED CONTACT ARM for uniform, unchangeable contact pressure. Easy and smooth to operate.
PROTECTED & UNPROTECTED
TUBULAR RHEOSTATS
and
POWER RESISTORS
REX RHEOSTAT CO.
BALDWIN, L. I., N. Y.

AMTHOR Dead Weight Pressure Gauge TESTER

Type 452



Modern design and construction puts this rugged precision instrument in a grade above the ordinary dead-weight testers.

Made in ten ranges, to 5000 lbs. maximum.

We guarantee 1/10 of 1 percent accuracy in each range.

The Type 452 is designed for simplicity and compactness. It incorporates the newest refinements and improvements. Adapters and tools are supplied, as well as either carrying case or protecting cover.

Immediate and intelligent attention will be given to your inquiries on all industrial speed measurement problems.

Drop us a line today.

Amthor Testing Instrument Co., Inc.
49a Van Sinderen Ave. Brooklyn, N. Y.

said to have an exceptionally large safety factor. Resistance element is a thick, solid-molded ring, heat-treated under pressure—not a sprayed film or paint type resistor—so that unit is unaffected by heat, cold, moisture, or length of service. Terminals are embedded in resistance element. All parts are corrosion-resistant. Unit is available in sixteen stock resistance values from 50 ohms to 5 megohms with a linear taper. Five stock values from 0.1 megohm to 2.5 megohms are available in a clockwise logarithmic taper. Three stock values, 10,000, 25,000, and 50,000 ohms are available in a counter-clockwise logarithmic taper. Unit is 1 1/16" in diameter and extends 9/16" behind panel.—*Ohmite Mfg. Co., 4974 West Flournoy Street, Chicago 44, Ill.*

Please mention number 967 when filling out card

Hoist Load Indicator

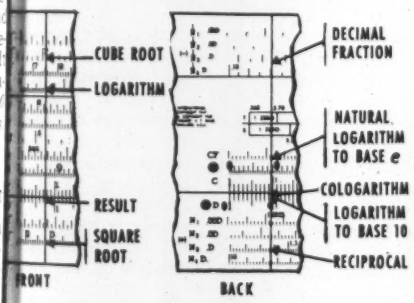
New "Dillon Dynamometer Scale" fits hoist hook, shows load weights instantly and accurately, saves double

handling. Capacity range of models is from 0-500 lbs. to 20,000 lbs. Weights are easily read on large dial.—*W. C. Dillon & Co., Inc., 5410 W. Harrison St., Chicago 44, Ill.*

Please mention number 968 when filling out card

Slide Rule

New "Deci. Log Log" silde rule simplifies computation: scales on front of rule are so arranged that only one set-

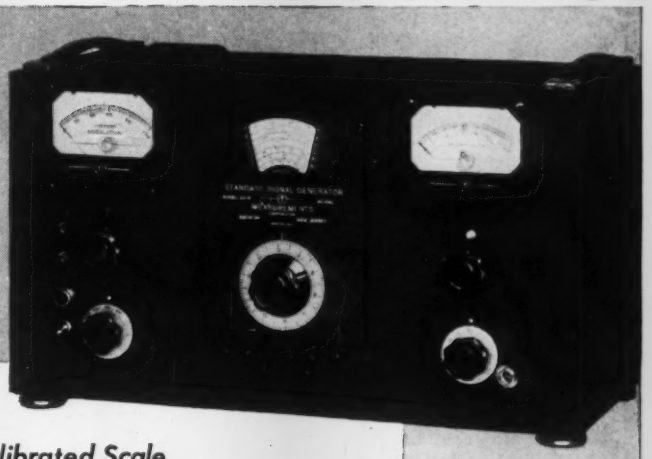


ting of hairline gives with each result its square root, cube root and logarithm. Log log scale on back is expanded for greater accuracy, gives five readings with each setting of the hairline: (1) decimal fraction to 4 and 5 figures; (2) its reciprocal to 4 and 5 figures; (3) logarithm; (4) cologarithm; (5) natural logarithm. Scales are "expanded": read from one ten-

STANDARD SIGNAL GENERATOR

MODEL 65-B

RANGE 75 KC to 30 MC



Individually Calibrated Scale

OUTPUT: Continuously variable, .1 microvolt to 2.2 volts.
OUTPUT IMPEDANCE: 5 ohms to .2 volt, rising to 15 ohms at 2.2 volts.
MODULATION: From zero to 100%. 400 cycles, 1000 cycles and provision for external modulation. Built-in, low distortion modulating amplifier.
POWER SUPPLY: 117 volts, 60 cycles, AC.
DIMENSIONS: 11" high, 20" long, 10¼" deep, overall.
WEIGHT: Approximately 50 lbs.

Catalog on request

MEASUREMENTS CORPORATION
BOONTON NEW JERSEY

MANUFACTURERS OF
Standard Signal Generators
Pulse Generators
FM Signal Generators
Square Wave Generators
Vacuum Tube Voltmeters
UHF Radio Noise & Field Strength Meters
Capacity Bridges
Megohm Meters
Phase Sequence Indicators
Television and FM Test Equipment

It's "Touch and Go"!

with the CORBIN Hand Tachometer

NO LAG . . . the pointer swings around instantly — follows every change of speed, giving a positive, steady reading at all times. CORBIN cross-balanced centrifugal governor eliminates oscillation . . . mechanism requires no lubrication. Packed in box with rubber pointer, rubber cup and rubber-tired wheel. Choice of ranges and dial markings.

Corbin Screw Division
American Hardware Corp.
New Britain, Connecticut

PA-2

Accurate CORBIN Tachometers

DEPENDABLE POWER FOR INSTRUMENT APPLICATIONS

One quality that is important in any instrument is its ability to provide records or indications which will be accurately reproduced under the same circumstances later. Therefore, all parts of the instrument must be planned to avoid unnecessary variation.

Bodine motors are widely used in instrument applications because they provide the utmost dependability. Users usually forget their instruments have motors because these motors are consistently trouble-free. The two motors shown—Bodine Type K motors with and without speed reducers—are favorites for inclusion in all types of indicating and recording instruments requiring low power, compact size, and extreme reliability.

If you have a particular motor application problem, Bodine engineers will be glad to work with you. Bodine Electric Co., 2244 W. Ohio St., Chicago, Illinois.

BODINE FRACTIONAL HORSEPOWER MOTORS

STATHAM GAGE
MODEL G1

Incorporating the same reliable gage unit as the Model YE, the new Model G1 is smaller, lighter and more rugged.

Displacement up to ± 0.0015" can be measured to a few microinches. Several models cover the force range of ± 2 oz. to ± 45 oz. Their stability makes these precision instruments ideal for incorporation into testing equipment. Their output is sufficient for operation of panel type microammeters, cathode ray oscillographs, recording potentiometers or galvanometers, usually without amplification. Resistive in electrical character, they are excellent for use with carrier systems.

The power supply may be as simple as a few dry cells.

Size: 2" x 1¾" x 29/32"

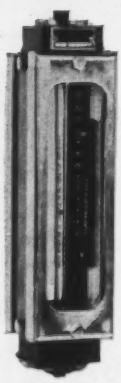
Weight: 2¼ oz.

Our engineering department is at your service to analyze and assist with your problems.

Write for Catalog.

STATHAM LABORATORIES
SCIENTIFIC INSTRUMENTS
8222 BEVERLY BOULEVARD
LOS ANGELES 36, CALIF.

The Full-View ROTAMETER



Maintenance "whoas"

Things that halt maintenance expense in the Full-View rotameter are (1) its dowel pin construction that makes it easy to take apart or put together, (2) its modernized, two-piece gland follower that prevents leakage, (3) use of stainless steel for dowel pins, cap screws, gland bolts and window frames. It will cut *your* rotameter maintenance costs, too. For full information, write for Folder #20, Brooks Rotameter Company, Box A-5947, Lansdale, Pa.

BROOKS ROTAMETER CO.
LANSDALE, PA.

billionth to ten billion and g... decim... point location. A simple le... nd te... which **scale to read** when rais... g to pow... ers. Slide rule is 12⅛" × 2... is made of magnesium alloy w... h plas... surface bearing easy-to-read washa... scales. It comes complete wit... carryi... case, illustrated Instruction Manual ... of Typical Problems.—*Picket... & Ecl... Inc., 5 S. Wabash Ave., Chic... 3, I...*

Please mention number 969 when filli... card.

Helical-gear Lead Checker

New improvements are announced ... "Model Sine-Line Lead Checker," ... takes gears up to 14" diam. and up ...

12" between centers (larger lengths ... special order). Its indicator reads ... 0.0001". It checks spiral lead rath... than helix angle, since spiral lead de... not vary as does helix angle in relati... to depth at which the check is made. ... uses sine bars to avoid possibility ... errors from inaccurate lead screws ... gear mounting.—*Michigan Tool C... 7171 E. McNichols Road, Detroit ... Mich.*

Please mention number 970 when filling out card.

Aircraft Engine Tachometer and Hour Meter

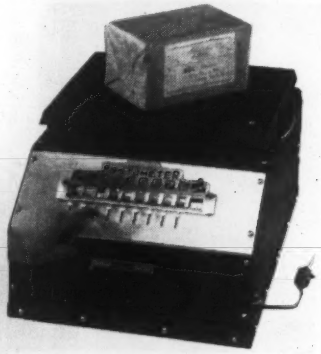
New "Tacholog" is a combinati... tachometer and engine-hour record... which obviates need for keeping an e... gine log by totalizing engine hou... based on the average cruising speed ... 2000 rpm. It is said to give unusual... accurate indication of engine wear, ... engine hours are counted at a slowe... rate when engine is idling and mo... rapidly when engine is operated at ... speed higher than stated cruisin... speed. Since a simple conversion give... equivalent hours for various othe... cruising rpm., unit is suitable for a... types of aircraft. "Tacholog" is mad... either with counter-clockwise or cloc... wise tachometer drives. It is said to b... lighter in weight than tachometers pr... viously available. (Owners of persona... aircraft will appreciate elimination ... a separate engine time recording in... strument and the lighter weight of th... new combination instrument.) Anothe... advantage is that instrument does n... have any adverse effect on compas... even when the two are installed sid... by side. "Tacholog" fits AN standar... 3⅛" mounting hole; connection i... standard SAE ⅞—18 T/I screw type... New aircraft tachometers, without th... engine hour recorder, lighter in weigh...

and incorporating improved engineering features, are also announced.—*Kollsman Instrument Div., Square D Co., 80-08 45th Ave., Elmhurst, N. Y.*

Please mention number 971 when filling out card

Computing Scale

New "Model 4601 Detecto Post-O-Meter" is a completely automatic computing parcel post scale. Computed re-

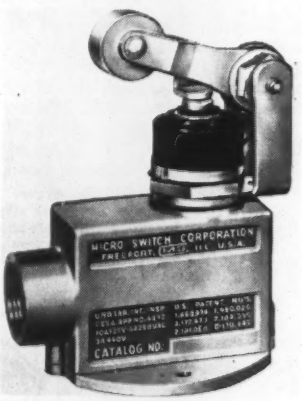


sult on illuminated drum chart is made visible by a simple zoning keyboard. When operator presses down the desired zone key, the computed figure (and only that figure) comes into view. Capacity, 70 lbs.; sensitivity, 2 oz. Drum chart is replaceable should postal rates and regulations change.—*Detecto Scales Inc., New York, N. Y.*

Please mention number 972 when filling out card

Sealed Switch

New "Type N2 Die Cast Enclosed Precision Switch" with adjustable roller arm actuator is for use in industrial equipment where the switch is exposed



to dust, dirt, abrasives and occasional splash of oil and water. It is designed particularly for cam and slide actuation on industrial applications. Roller arm actuator is adjustable both vertically and horizontally. Switch is supplied with either bottom mounting or side mounting facility. Synthetic rubber boot covering operating plunger and gasket assembled between bottom plate and housing case provides a completely sealed switch unit, when conduit hub is fitted with rigid conduit. Operating force, 6 to 16 oz.; release force, 4 oz. min.; pretravel, $1\frac{1}{64}$" max.; overtravel, $\frac{7}{32}$" min.; movement differential, 0.006" max.; net weight, 0.64 lb. max.—*Micro Switch, Freeport, Illinois.*

Please mention number 973 when filling out card

NEW! FM SIGNAL GENERATOR MODEL 202-B

FREQUENCY RANGE
54 to 216 MEGACYCLES

The model 202-B is specifically designed to meet the needs of television and FM engineers working in the frequency range from 54-216 mc. Following are some of the outstanding features of this instrument:

RF RANGES—54-108, 108-216 mc. ± 0.5% accuracy.
VERNIER DIAL—24:1 gear ratio with main frequency dial.
FREQUENCY DEVIATION RANGES—0-80 kc; 0-240 kc.
AMPLITUDE MODULATION—Continuously variable 0-50%; calibrated at 30% and 50% points.
MODULATING OSCILLATOR—Eight internal modulating frequencies from 50 cycles to 15 kc., available for FM or AM.
RF OUTPUT VOLTAGE—0.2 volt to 0.1 microvolt. Output impedance 26.5 ohms.
FM DISTORTION—Less than 2% at 75 kc deviation.
SPURIOUS RF OUTPUT—All spurious RF voltages 30 db or more below fundamental.

Write for Catalog D

This instrument was described editorially in November ELECTRONICS—reprints available on request

BOONTON RADIO Corporation
BOONTON·N·J·U·S·A·
DESIGNERS AND MANUFACTURERS OF THE Q METER · QX CHECKER FREQUENCY MODULATED SIGNAL GENERATOR BEAT FREQUENCY GENERATOR AND OTHER DIRECT READING INSTRUMENTS

The Smartest 3¢ You Ever Invested!

Three pennies in postage will bring you *the* answer to *real* cost reductions in marking wires, leads, circuits, relays, parts, etc.

• As alert production, maintenance, and repair men everywhere have discovered, *QUIK-LABELS* do the job better, faster and cheaper than string tags, roll tapes, decals, stencils, metal tabs, etc.

You can't afford not to look at *QUIK-LABELS* . . . particularly when a 3c stamp will bring you FREE SAMPLES by return mail. Clip that convenient coupon *now*. W. H. BRADY COMPANY — *Identification Specialists* — Milwaukee, Wisconsin.

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Please send me FREE samples of QUIK-LABELS, the modern time and money saving way to mark wires, leads, circuits, relays, parts, etc.

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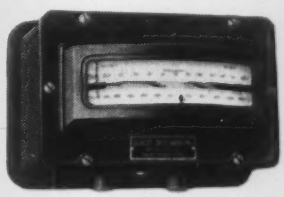
Wall-Type
INDICATOR PYROMETER

A PRODUCT OF 40 YEARS OF RESEARCH



Model W-1
Switchboard Indicator

Unskilled help may handle this direct-deflection instrument, which needs no manual adjustment. Designed for numerous ranges of temperature, both F. and C.

Write for descriptive Bulletin 400

Charles Engelhard, Inc.
233 N.J.R.R. Ave. Newark 5, N. J.

FOR TEMPERATURES AND PRESSURES

This is the new Brown *Electr-o-Vane* Control Unit. To users of electric contact control Thermometers and Pressure Gauges, it offers a high degree of control performance never before attained.

A true triumph in control, this electronic unit is not merely an adaptation of a known principle but an achievement in design by which all the shortcomings of similar devices are eliminated.

Added to the Brown Thermometer and Pressure Gauge line, the *Electr-o-Vane* Unit provides a control instrument of unequalled performance. No instrument of this type can equal its dependability in service, its precision in operation or its safety features.

Brown *Electr-o-Vane* Thermometers and Pressure Gauge Controllers are available *at no premium cost*. With all the exclusive features of these instruments, why compromise with less than the best.

A NEW CATALOG (No. 6001) fully describing the operating principle, features and models of the Brown *Electr-o-Vane* Controllers is now available. Write for your copy today—there is no obligation.

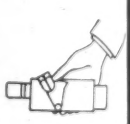
The Brown Instrument Company 4482 Wayne Ave., Philadelphia 44, Pa.
DIVISION OF MINNEAPOLIS-HONEYWELL REGULATOR CO.
SUBSIDIARY COMPANIES IN TORONTO : MEXICO CITY
LONDON : STOCKHOLM : AMSTERDAM : BRUSSELS

HERE ARE THE FACTS

The Brown *Electr-o-Vane* Control unit operates on the principle that when a metal vane is interposed between two oscillator coils in a unique electronic circuit, the oscillations stop. The stopping of oscillations causes the electronic circuit to operate a load relay.

The oscillator coils are the heart of the controller. Brown oscillator coils are molded in bakelite and are thus *moisture-proof*—an exclusive Brown feature. A knife-edge control action is precise. It never varies. It is unaffected by moisture conditions.

Only the circuit used in the Brown *Electr-o-Vane* Control Unit causes an actual stop in oscillations. That is why this is the only instrument of its type providing real *snap action*—an important factor for precision control.



Brown *Electr-o-Vane* Control is contained in a neat, compact unit. It is self-contained, easily removed as a unit and unaffected by dust or dirt.

Electr-O-Vane

THERMOMETER CONTROLLERS

PRESSURE GAUGE CONTROLLERS

JOURNAL of the Instrument Society of America

Editor, R. R. PROCTOR, 2213 Ridge Ave., Evanston, Ill.
I.S.A. National Office, 1117 Wolfendale St., Pittsburgh 12, Penna.

Vol. 2 SEPTEMBER 1947 No. 9

Editorial

"HOTTER TOMORROW . . ."

As this is being written, it doesn't take a couple of instruments nor even the radio to tell us that the temperature is 99 and the relative humidity close to 90! We are enough of a thermometer and/or a psychrometer to measure those conditions pretty accurately, and consequently to realize why we are so hot and uncomfortable. We would do anything within reason to get away from it—we would gladly avoid editorializing in this issue if possible. Ironically enough, however, we have in spite of the heat chosen to "build a little fire" (editorially speaking), and reference to our editorial entitled "Co-operation" in the February (1947) issue of the *Journal* will reveal our intent.

In fact, we could save a lot of words in the following paragraphs if we just requested everyone to go back and read that editorial again. We hope we can turn on enough heat in this attempt to make some other people do anything to get away from it. That "anything" is the expenditure of just a little time.

Whether due to vacations, the nation-wide heat wave, flying saucers, or just general procrastination, considerable laxness has been encountered in the last two or three months among the people to whom we have addressed requests for information and material for the *Journal*. We cannot help but wonder if other requests or letters from the National Office and other sources have been treated similarly. Therefore, this may be considered the first of the "fires" to which reference was made in the above-mentioned February editorial. (Naturally this does not apply to those who did respond promptly or who otherwise have cooperated to the best of their ability.)

About 40% of the material solicited for the *Journal* recently has been submitted on schedule. The rest of it is still to come! For example, we have mailed as many as five and six monthly "reminders" to some people in following up our original request for biographical information for our "Who's Who" articles. A considerable amount of that information is still missing. Likewise, we have failed to receive from a number of Sections the filled-out forms listing officers, delegates, *Journal* correspondents, meeting dates and other pertinent information concerning the Sections which it is important to have in our reference file.

Except for making our editorial job a little more difficult, failure to respond to these requests does not hurt us personally, but it does retard cooperation and interchange of ideas and benefits between the delinquent Sections or individuals and the rest of the Society. Any person (or Section) can benefit from I.S.A. affiliation only to the extent of the cooperation he (or it) is willing to practice when the occasions arise. Publicity—through the columns of the *Journal*—is one of the more easily obtained benefits, but even that requires some cooperation.

This, then, is an appeal to all the "guilty" Sections and individuals to dig out the various requests, forms and reminders sent them in the recent past and do something about them as soon as possible. Now that the Chicago Conference is over, vacations are (in most cases) but memories, and new hands are at the wheel in various posts in many of the Sections, the 1947-48 season should be started off with a resolution to cooperate 100% in all affairs of this nature, for the benefit of the Society, the Section and ultimately the individual.

Whether the request be from the Editor, a committee chairman, a Society officer or other individual, and whether the request be for material for the *Journal*, general or technical information, assistance in committee work, *or just an answer*, your co-operation in replying immediately will, besides being appreciated, make for a better So-

Continued on page 864

Editor's Notes

1. SMALLER ISSUE THIS TIME

It will be noted that this issue of the *Journal* is somewhat smaller than normal. We have three very good reasons for this, plus a couple of less good reasons which we shall insist are not alibis. The very good reasons are (1) Most of the Sections hold no summer meetings and consequently submit no Section News reports, with the result that our Section News Department contains but approximately one-fourth its normal lineage; (2) Much of the material at hand concerns the Conference of September 8-12 in Chicago, which affair will be history by the time this issue of the *Journal* is published—hence this material is unusable; and (3) *all* reports, news material, Board actions and other highlights of the Conference and Exhibit can be written up only *after* such events occur, and that will be about three weeks after the deadline for *this* issue. (And we lay no claims to clairvoyance.)

So much for the good reasons. The less good reasons are the hot weather and a vacation. And since the two of them coincided, with the deadline for this issue hot upon their heels (hot, literally!), the less said about them, the better.

2. WHO'S WHO AND WHERE!

In last month's issue (August) our "Who's Who" notice in the "Editor's Notes" column indicated that delegates Lee and Goetzenberger and Chairmen Brombacher and McCarthy were publicized elsewhere in that issue. Due to space limitations, the Goetzenberger and McCarthy write-ups had to be held over until this issue (September), but through an oversight the Editor's Note No. 1 was not changed to correspond to the new arrangement.

This, therefore, is an apology for the confusion thus caused in the last issue, and an explanation for the large group publicized in this issue.

Our "Who's Who" department this time consists of two members of the Board of Directors, one committee chairman and three sub-committee chairmen—six in all. The first is Ralph Goetzenberger, the Washington Section Delegate whose write-up should have, but did not, appear in last month's issue. In addition, we have with us this time Ken Mead, Delegate and one of the founders of the Southern Michigan Section at Kalamazoo and Battle Creek.

The committee chairman is Bill Wildhack, who heads up the Committee on Committees. Bill is one of the two Vice-Presidents of the Washington Section.

The three sub-committee chairmen are all members of "Trap" Trapnell's Recommended Practices Committee. Harold M. McCarthy (also carried over from last issue) is a member of the New Jersey Section and is chairman of the sub-committee on Recommended Practices for Thermocouples and Extension Wires. Robert L. Galley, a member of the Philadelphia Section, is chairman of the sub-committee on Flowmeter Installation Practices, and W. H. Fortney, of the Houston Instrument Society (not yet affiliated with the I.S.A.), is chairman of the sub-committee on Control Valves and Bypass Installation Practices. Brief progress reports from these two latter sub-committees appear elsewhere in this issue.

3. GUEST CARTOONIST!!

Carbide & Carbon at Charleston certainly turns up some versatile personnel! Our regular cartoonist, Gene Mitchell, hails from Ralph Webb's Instrument group there, and this month we have an offering submitted by another gentleman from the same plant—J. E. McClure of the Operating group. It seems that Mr. McClure, believing that one picture is worth a thousand words, drew up a complete set of sketches to aid him in instructing a group of new operators. One sketch appealed so to the Instrument group that Ralph Webb thought it might interest others. Accordingly, he secured "Mack" McClure's permission to reproduce it, and submitted it to the *Journal* a few weeks ago. It is our pleasure to forward this "vital message" to our readers in this issue—and

thanks to Mack and Ralph for the privilege.

OPERATORS DON'T OPERATE ON INSTRUMENTS

CALL THE INSTRUMENT MAN!

4. ANOTHER SECTION

A last-minute announcement from Secretary Rimbach, barely making the deadline on this issue, informs us that the Sarnia Instrument Association of Sarnia, Ontario, Canada, has applied for a charter as a Section of the I.S.A. By the time this appears in print, action on this application will probably have been taken by the Board of Directors at the annual meeting in Chicago on September 6th. Our heartiest welcome to what will be the 33rd Section of the I.S.A. *(Please note: The Secretary received a charter application from Tulsa after the material was received from the Editor.)*

5. THE NEEDLE POINTS TO—

Detroit, for what we consider the best of the five Section News reports submitted this month. Newsy and smooth, it required the least editing, and may well serve as an example for our new Sections and for those others which have seldom or never submitted news material to this office.

—R. R. Proctor.

Official News Department

TO ALL SECTION SECRETARIES

A new and as complete as possible list of Section Secretaries, Delegates and JOURNAL Correspondents is to be published shortly, but to keep the last list up-to-date, the following additional changes should be made:

CINCINNATI: Secretary and *Journal* Correspondent—Robert F. Romell, Vulcan Copper and Supply Co., 120 Sycamore St., Cincinnati, Ohio; Delegate—H. Gordon Morgan, Foxboro Co., American Bldg., Cincinnati, Ohio.

CUMBERLAND: New *Journal* Correspondent—G. William Harrison, Hercules Powder Co., Box 210, Cumberland, Md.

DETROIT: Acting Secretary—President V. G. Raviolo (Ford Motor Co.), Horace H. Rackham Bldg., 100 Farnsworth, Detroit 2, Mich.; New *Journal* Correspondent—W. E. Wilson, 21615 Middle Belt Road, Farmington, Mich.

WAYNE COUNTY: New Secretary—George Rogers, P.O. Box 150, Wyandotte, Mich.

Proceedings of the I.S.A.

DISTRIBUTED IN JULY

The long-heralded "Proceedings of the Instrument Society of America" made its appearance the latter part of July and has been mailed to all members in good standing as of the date of publication. This booklet, which is to be an annual publication, contains the papers presented before the 1946 Conference held in Pittsburgh last September, and will thus serve as valuable reference material.

Many factors, including "growing pains confusion," conspired to cause a much later publication date for the Proceedings than was originally intended. However, it is expected that this situation will be eased in the future and that the Proceedings will be published at a considerably earlier date. The next issue will include the papers presented at the 1947 Conference in Chicago, together with some of the discussions and other material as selected by the Publications Committee.

PROGRESS REPORT OF SUBCOMMITTEE ON FLOWMETER INSTALLATION PRACTICES

The Recommended Practices Committee subcommittee on Flowmeter Installation Practices held a meeting on August 5th, 1947, in Philadelphia, the chairman presiding. The membership of the group at that time consisted of Robert L. Galley (American Viscose Corporation), chairman; John W. Johnston, Jr. (E. I. duPont de Nemours & Co.); Herman W. Bocher (Philadelphia Coke Co.); and Hugh L. McCulley (Atlantic Refining Co.).

(Ed. note—Some additional members were added, and another meeting held prior to the Chicago Conference, but details were not available at this writing.)

The efforts of the committee are now being concentrated on steam condensate chambers and seal-pots, with a view to reducing the large number of various shapes, sizes and designs now offered by the flowmeter manufacturers.

Plans for future activities of the committee include developing recommended practices for all phases of flowmeter installations not now covered by any other set of standards. Examples are (1) Standardization of stamped data on orifice plates, (2) Recommended panel mountings for flowmeters, (3) Proper and improper purge hook-ups, and (4) Recommended drop-legs for installation of flowmeters above orifice plates.

—ROBERT L. GALLEY, *Chairman, Flowmeter Installation Practices Subcommittee.*

INTERIM REPORT OF SUBCOMMITTEE ON CONTROL VALVES AND BYPASS INSTALLATIONS

The work of this subcommittee of the Recommended Practices Committee has been handled largely by correspondence to date, and has consisted chiefly of obtaining opinions and information. A group of Instrument men, mostly in the Gulf Coast area so far, have been circularized with a questionnaire and a series of sketches. The results of the answers received have been tabulated for presentation at the meeting of the Recommended Practices Committee on September 8th in Chicago.

(Ed. Note—A more complete report containing this tabulation summary will be published when the information is released as soon as possible after the Chicago Conference.)

Since it is desirable to have committee personnel selected from a not-too-large geographical area, and since there are but few I.S.A. members in the Baytown and Houston area, the membership of this subcommittee is not yet stabilized. This situation will be remedied, however, as soon as enough information has been accumulated to require frequent committee meetings.

—W. H. FORTNEY, *Chairman, Control Valves and Bypass Installations Subcommittee.*

Section News

ARUBA

With President Art MacNutt on vacation in the United States, Acting Chairman Ed Pfeffer called our 13th meeting to order at 7:15 on August 5th, 1947. The Secretary reported that in answer to our requests we have begun to receive Society business items and correspondence by air mail. This cooperation of the Executive Secretary and others in the National organization will enable us to take more active part in all current Society affairs.

The following reports were [illegible] sented in lieu of a technical tal[illegible]

M. A. Davidson, our repres[illegible] the Community Council, report[illegible] activities in our interest on the [illegible]

Bill Weber presented a report [illegible] tus of the treasury, and then [illegible] over formally to our regular Trea[illegible] Koopman, who has just returned [illegible] vacation in Europe.

Bill Hughes, our Delegate to [illegible] of Directors quoting from a re[illegible] from the National Nominating [illegible] read a list of those who have b[illegible] nated for the national offices of [illegible] and Vice-President.

The Entertainment Committee announced the names of those who were "appointed" to supply the sandwiches and coffee for the next meeting. The committee's [illegible] for the coming year were approved by those present.

The Membership Committee welcomed our new members on behalf of the membership, and the Housing Committee reported on their endeavors and obtained opinions of members in regards to a proposed housing collaboration with a local organization.

Stan Chapman, our Recommended Practices Committee Chairman, brought us up to date on his committee's activities.

Ed Hillstead presented a report on his visit to the May meeting of the Kansas City Section. The reception and attention which he received were appreciated and we feel that Ed's visit was well worth any effort on our part to make such arrangements.

Bill Koopman gave us a report on his visit with the Honorable Secretary of the Society of Instrument Technology (England), Mr. L. B. Lambert. Bill contacted Mr. Lambert in London while on a short trip to that country. Due to transportation arrangements, Bill was forced to forego the pleasure of meeting other members of the S.I.T. According to Mr. Lambert, the S.I.T. which compares with the I.S.A., expects to have some 3000 members by the end of the next two-year period.

Halpert, our member who has just returned from a vacation in the Balkans gave a brief report on his travels.

The Program Committee produced some information on an Electronics Course, and then presented the Westinghouse film "Electronics at Work," which was obtained through the courtesy of the American Consulate here.

After the showing of the film we adjourned to the "snack bar," where we enjoyed coffee, cookies and sandwiches through the kindness of Mesdames Davidson and Holly.

Incidentally, on the copy of the agenda of the meeting which each member received several days in advance, an allotted time was shown for each item. This seemed to work out very well and we intend to continue this procedure.

—L. J. LOPEZ, *Corr.*

CINCINNATI

Officers for the 1947-48 season are as follows:

President—Smith Hickenlooper, Jr., Procter & Gamble Co., Ivorydale, Ohio.

Vice-President—T. L. Clift, Sohio Petroleum Co., Latonia, Ky.

Treasurer—Yeatman Anderson, Foxboro Co., Cincinnati.

Recording Secretary—S. Ted Isaacs, Drackett Co., Cincinnati.

Corresponding Secretary and JOURNAL Correspondent—Robert F. Romell, Vulcan Copper Co., Cincinnati.

National Delegate—H. Gordon Morgan, Foxboro Co., Cincinnati.

—R. F. ROMELL, *Corr.*

DETROIT

A novel type of program was successfully tried at the June meeting of the Detroit Section. Under the title of "Pneumatic Brains—Key to Low Cost, High Quality Production," three speakers presented brief and concise accounts of their companies' activities in that field. Since each talk was limited to about 30 minutes, a relatively large portion of the meeting time remained for the question and answer period which proved to be equally as interesting as the lectures themselves.

The evening was under the technical chairmanship of Mr. L. B. Bellamy, President of the Detroit Chapter of the A.S.T.E., who introduced the speakers. The first speaker was Mr. D. Kirk of Moore Products Company, who described several pneumatic gaging circuits and their adaptability to standard machine tools.

A rather specialized gaging mechanism was described by the second speaker, Mr. E. Kline, executive engineer of the Mimatic Hone Company. Used to gage the work piece itself rather than the tool performing the work, the "Hydrosize" circuit embodies a balanced diaphragm and a microswitch in its size control valve.

Mr. Beer of the Monarch Machine Tool Company rounded out the evening with slides and motion pictures explaining the operation of the Monarch Air Tracer which uses a template to turn the workpiece along a predetermined contour.

The July program was the annual picnic held jointly with the Wayne County Section.

W. E. Wilson of Nash-Kelvinator has been appointed Editor of the Section publication, The RECORDER, and will also take over the duties of JOURNAL Correspondent. Section Secretary-elect Robert W. Gardner will be unable to serve in that capacity, and as yet a replacement has not been elected. President Victor G. Raviolo is acting as Secretary for the present.

—SIEGMUND KULKA, *Treas., Past Corr.*

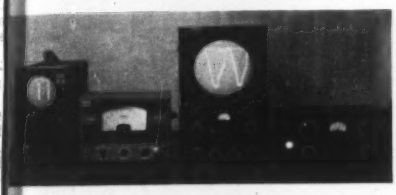
CUMBERLAND

The Cumberland Section held a special technical meeting the evening of July 10, 1947. The speaker of the evening was Mr. Harry Stern, head of the Instrument Department of the Hercules Powder Company, who gave a lecture and demonstration on various applications of the cathode-ray oscilloscope. Mr. Stern's talk covered the following applications in particular:

As used in measuring pressures with resistance wire strain gages;

As applied to high speed temperature recording;

Other applications such as in measuring light intensity and instantaneous voltages.



Some of the demonstration equipment used by Mr. Harry Stern at his recent appearance before the Cumberland Section.

A lively period of discussion, questions and answers followed the general meeting.

—JOHN S. KELLY, *Corr.*

OAK RIDGE

The regular August 5th meeting of the Oak Ridge Section featured Mr. B. E. Rector of Westinghouse Electric Corporation of East Pittsburgh, Penna., as guest speaker.

Following dinner at Grove Hall, the business meeting was called to order at 8:00 p.m. by President A. A. Novak. The minutes of the last meeting were read by A. J. Thompson in the absence of Secretary Fowler. J. R. Mahoney of the Program Committee reported on meetings for the next two months. After some discussion, a motion was made and passed to investigate two other possible meeting places in Oak Ridge since it is no longer possible to meet at the Grove Hall.

The Nominating Committee then presented its slate of candidates for the annual election of officers in September.

Mr. Rector began his talk on "Dielectric and Induction Heating" with an explanation of the differences between the two types of heating, pointing out that a comparatively low rf frequency was employed in induction heating and a higher frequency in dielectric heating. Several slides showing fundamental circuits and component parts of each type of heating apparatus were shown. The design and construction of coils, converters and oscillators were discussed, and it was pointed out that induction heating could be employed to heat treat, harden, braze and solder many types of metals, alloys, and conductors.

Dielectric heating, as was shown, is used to heat non-conductors such as wood, plastics and rubber compounds. Several applications of this type of heating were discussed and shown by slides.

The talk was completed with the showing of a sound movie on the two types of industrial heating.

L. C. Balch of the Knoxville, Tenn., office of Westinghouse, was a guest at the meeting. Also several representatives of the Bureau of Mines at Norris, Tenn., were present as guests.

The September meeting will feature Mr. David H. Fuller of the Foxboro Company, speaking on "Trends in the Use of Electronics in Instrumentation."

The October meeting will be another forum with local Section members as speakers.

—CHAS. W. COVEY, *Corr.*

Who's Who in the I. S. A.

RALPH L. GOETZENBERGER
(Delegate, Washington Section)

A man who has been closely associated with instruments and instrumentation for practically his whole life, Ralph Goetzenberger was the logical choice of the Washington Section when the election of a National Delegate was necessary this year. Ralph was graduated from the University of Minnesota with a B.S. degree in Engineering in 1913, and in Electrical Engineering in 1914, also at the University of Minnesota. Shortly thereafter he became associated with the Minneapolis-Honeywell Regulator Company in Minneapolis, with which concern he has remained almost continuously to date.

Probably the best means of illustrating Ralph's recent background and present activities is as follows:

Vice-President, Minneapolis-Honeywell Regulator Company, Minneapolis, Minn.

Vice-President, Brown Instrument Company, Philadelphia, Pa.

Member, American Society of Mechanical Engineers (Chairman, Board of Education and Professional Status).

Member, Instrument Society of America, Washington Section (National Delegate).

Member, American Institute of Electrical Engineers, American Society of Engineering Education, Engineers' Council for Professional Development, Army Ordnance Association, Society of American Military Engineers, and the Washington Society of Engineers.

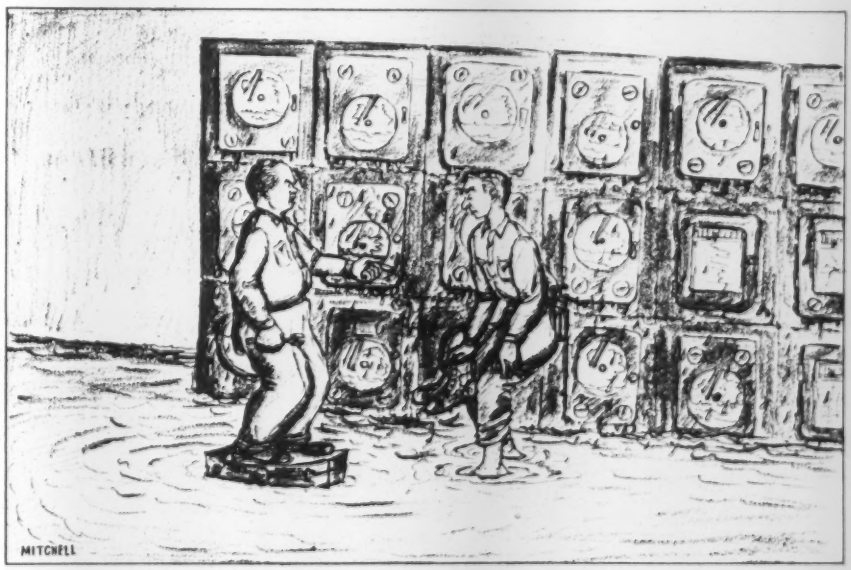
Ralph's business address is 1919 K Street N.W., Washington, D. C. (Minneapolis-Honeywell Regulator Co.) and his home address is 714 Norway Drive, Kenwood, Chevy Chase, Md. Due to his natural modesty, Ralph feels that a citation of past accomplishments, etc. (of which he can lay claim to many) constitutes "water over the dam." He prefers to let present acts and connections speak for themselves, and to be known as a loyal I.S.A. man who is doing his best to represent the Washington Section as it should be represented on the Board of Directors of the Society.

KEN MEAD
Delegate, Southern Michigan Section

Southern Michigan's Delegate, Ken Mead, was born on the first day of October, 1910, in Cloverdale, Michigan, and for the first ten years of his life apparently didn't do very much. However, when he was ten years old, his Christmas present consisted of the parts for a one-tube, three-circuit regenerative radio receiver, and Ken hasn't had an idle moment since. After building radios for several of his neighbors, a profitable business developed which helped put him through high school, from which he graduated as a Science and Math major.

Came the crash of '29 and Ken's plans to enter college were blasted, so he went to work for the American Electrical Appliance Company in charge of an assembly of small electrical appliances, some of which he helped design. Shortly, however, he joined the Consumers Power Company of Kalamazoo, where he spent the next seven years in the Electric Distribution Department, installing and servicing major electrical appliances and commercial and domestic refrigerators.

In 1942 Ken joined the Engineering Department of the Allen Electric and Equipment Company, where he is located at present. In 1943 he was given the job of organizing an Electric Meter Repair Department. His work with the Engineering



"Are you SURE that was INSTRUMENT AIR you hooked to these instruments???"

Department in the design of a D'Arsonval type moving coil d-c milliammeter soon brought him the responsibility of putting same into production, supervising the design and construction of all jigs and fixtures and necessary test equipment, and training operators for the job.

During all these years, Ken furthered his education by courses in Electronics with the National Radio Institute, Electrical Engineering with I.C.S., and a year's apprenticeship in tool and die making to supplement a four year night school course in drafting.

He was one of the men instrumental in organizing the Southern Michigan Section of the I.S.A., serving as Secretary and *Journal* correspondent during the 1946-47 season. He was elected to the offices of Vice-President and Delegate for the 1947-48 season.

Ken is married, has a daughter 3 years old, and likes fly-tying, fly fishing and hunting when time permits.

W. A. WILDHACK

Chairman, Committee on Committees

William A. "Bill" Wildhack, Vice-President of the Washington Section, joined the National Bureau of Standards in Washington in 1935 with a B.S. in Mechanical Engineering, an M.S. in Physics (University of Colorado), and several years of teaching experience in the fields of engineering and physics.

His position is that of Physicist, Mechanical Instruments Section, in which capacity he has worked on aeronautic instrumentation, developed oxygen equipment test apparatus, etc. Some of the many papers Bill has had published are on such subjects as Oxygen Requirements at High Altitudes, Optimum Time Delay for Parachute Opening, Corrugated Diaphragms for Pressure-Measuring Instruments, etc.

Besides being a member of the I.S.A., Bill is a member of the Institute of Aeronautical Sciences, American Association of Physics Teachers, Washington Academy of Sciences, Philosophical Society of Washington, and the Washington Association of Scientists. In addition he serves as Associate Editor on the staff of The Review of Scientific Instruments.

In I.S.A. activities, Bill has been most active. He served on the Board of Directors as the Washington Delegate, 1944-46; as Chairman of the Publications Committee, 1945-46; and as Chairman of the Committee on Committees, 1946-47. This latter committee completed its first major project by formulating the statements of the function and scope of all other I.S.A. committees, and submitting these articles to the Board of Directors at the meeting in Cleveland this past April.

(Further reports on the activities of this committee, or its successor—it has been recommended that the name of the committee be changed—will be published following release of the minutes of the Board Meeting held on September 6th, 1947.)

HAROLD M. McCARTHY

(Chairman, Subcommittee—of Recommended Practices Committee—on Thermocouples and Thermocouple Extension Wire)

"Mac" McCarthy was born in Brooklyn, New York, late enough not to have yet reached the age when "Life Begins at . . ." He attended the public schools in that fair city until he journeyed to Atlanta, Ga., to study Electrical Engineering at Georgia Tech. He was graduated in 1932 only to learn that jobs in those days were hard to find.

After almost a year of peddling a well-known make of oil furnace designed for domestic heating, Mac located a job in the Development Laboratories of C. J. Tagliabue Manufacturing Company under the able guidance of C. O. Fairchild, the present President of the I.S.A.

He resigned from Tag in 1936 for employment with the Standard Oil Development Company as an Instrument Engineer. He has remained with this company ever since except for an interval from June, 1941, until October, 1945, when he served with the U. S. Navy in numerous capacities in the Atlantic and Pacific as a technical officer on electronic equipment. With the war over, the Navy put him on inactive duty as a Lieutenant Commander and he returned to Standard Oil Development to resume his work as Instrument Engineer. Shortly thereafter he was put in charge of a group of engineers handling the engineering and procurement of industrial instruments for the measurement and control of continuous petroleum refining processes.

Mac is a member of the New Jersey Section of the I.S.A. and is currently serving as its Publicity Chairman and JOURNAL Correspondent. He is a member of the national I.S.A. Recommended Practices Committee, and Chairman of the subcommittee preparing recommended practices for thermocouples and thermocouple extension wire (color coding, etc.). Some of the recommendations of this committee are scheduled for publication and release in the near future for inclusion in the I.S.A. Data Binder which will soon be distributed by the Publications Committee.

For hobbies, golf is Mac's principal interest, although he hopes to take up sailing before long. Bon Voyage, Mac.

ROBERT L. GALLEY

Recommended Practices Committee, Chairman, Subcommittee on Flowmeter Installation Practices

Bob Galley's instrumentation experience dates from 1928 when he went to work for Bailey Meter Company after graduating from the University of Michigan. While with Bailey, Bob spent a year at Ohio State University on orifice coefficient research.

Followed then a period during which he branched off into power survey and design work at B. F. Goodrich Company, Akron, Ohio, and E. I. duPont de Nemours & Company at the Indiana Ordnance Works, Alabama Ordnance Works, and Grasselli Chemical Division. A brief period was then spent in instrument sales around Philadelphia, Wilmington and Baltimore, following which Bob took his present job as Instrument Engineer for American Viscose Corporation at the close of the war.

Bob is married and has four children ranging from 3 to 13 years of age. Outside of raising young Americans, his only other hobbies are water sports and reading. He is a member of the Philadelphia Section of the I.S.A. and was appointed a member of the Recommended Practices Committee in 1946. Shortly thereafter he was asked to head a subcommittee to develop recommended practices for flowmeter installations.

A brief report of the activities of this subcommittee will be found elsewhere in this issue.

W. H. FORTNEY

Recommended Practices Committee, Chairman, Subcommittee on Control Valves and Bypass Installations

One of the few non-members of I.S.A. who are very active in I.S.A. affairs is W. H. Fortney, General Foreman of the Instrument Department, Baytown Refinery, Humble Oil and Refining Company, Baytown, Texas. Last year, however, he served as President of the Houston Instrument Society during its first year of organization, and since that organization is considering affiliation with the I.S.A., he may soon become an I.S.A. member. He could do no more for the I.S.A. as a member than he already has, however, to which the Association owes a vote of appreciation and thanks.

Mr. Fortney has been instrument work for nearly 24 years, starting with the Texas Company in 1923 after three years of Chemical and Electrical Engineering at the University of Texas. He has served in Electrical and Instrument Foremanship in small plants, becoming Foreman of the Baytown Refinery Instrument Department in March of 1937. This department has grown to meet the demands of a rapidly expanding plant (including a butadiene and a butyl rubber plant, and the Baytown Ordnance Works, during the war) from 35 to 170 men. Fortney and his foremen and engineers trained well over 200 instrument men during the war, including those who left the organization for other jobs, as well as outsiders who attended the courses. Incidentally, he is proud of the fact (and rightly so) that his department last April passed the one-millionth man-hour without a disabling injury!

Last year Mr. Fortney served as a member of the Steering Committee during the organization of a short course in "Instrumentation for the Process Industry" at A & M College of Texas, and is now serving his second year with this group. (The course offered this year was publicized in the August, 1947, issue or the JOURNAL. Ed.) He has authored two articles, one on "Requirements for an Instrument Department" which appeared in the February, 1947, issue of INSTRUMENTS, and one on "Field Heat Treating of Refinery Piping" in the *Petroleum Refiner*, xii 632. In addition, he has presented papers before the New Jersey Section of the I.S.A. (December, 1946), the Spring National Meeting at Cleveland (April, 1947), and the 1947 Conference in Chicago.

Mr. Fortney is a member of the Elks Lodge (has served as Exalted Ruler), and is and has been very active in local civic activities, having served at various times as Director of Welfare League (Community Chest), Director of Health Clinic, Director of Recreation Council, and President (two terms) of the Local Water Board—which was a substitute for municipal government before incorporation.

Mr. Fortney is married and has a son and two daughters; his son is a junior in college and his older daughter has just graduated from high school. Hobbies include loafing, elbow bending and fishing.

A brief progress report of Mr. Fortney's subcommittee on "Recommended Practices for Control Valves and Bypass Installations" was presented at the Spring meeting in Cleveland, and is summarized elsewhere in this issue.

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INSTRUMENT SERVICE ENGINEER. Growing manufacturer in Philadelphia, Pa., offers unusual opportunity to a young man who can service equipment and instruct customers in the maintenance of pneumatic controllers. Must be able to handle service correspondence. Write fully, stating education and experience. Box

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INSTRUMENT MECHANIC to maintain and repair all types of chemical manufacturing plant instruments, including flow and ratio controllers, temperature and pressure regulators, etc. Hourly basis. Location near Marcus Hook, Pa. Box 74.

. . .

INSTRUMENT ENGINEER by jet propulsion laboratory. Must be experienced in instrumentation for measurement of force, pressure, flow and the like. Previous experience with instrument manufacturer preferable. Location California. Box 75.

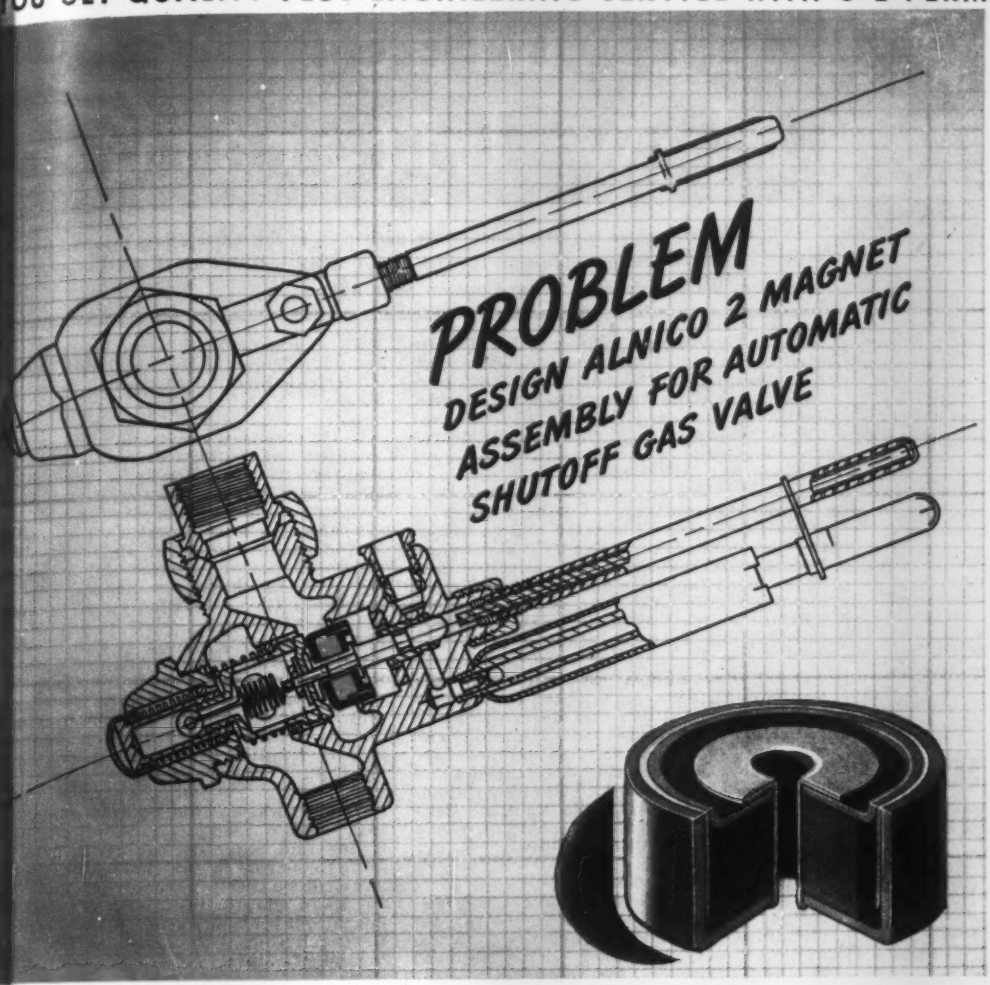
Editorial

Continued from page 861

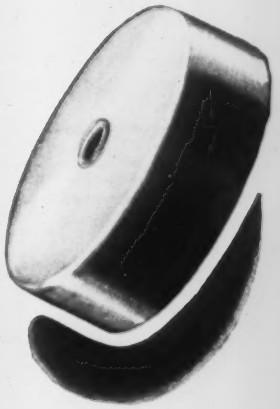
ciety and greater benefits for all, including yourself.

So, in the vernacular, the heat is on. If it is on YOU, a little cooperation will soon take it off. Otherwise, like the weather, it might be hotter tomorrow.—RRP

YOU GET QUALITY PLUS ENGINEERING SERVICE WITH G-E PERMANENT MAGNETS



Designed by G-E engineers, this ALNICO permanent magnet holding assembly insures positive snap action in the Titan 100% Shutoff Automatic Safety Pilot manufactured by the Titan Valve and Mfg. Co.



The Magnet that Safeguards your Gas Heater

Here's a magnetically controlled pilot light for your gas heater that's 100% safe. While the pilot flame is burning, the ALNICO permanent magnet assembly grips a steel ring, keeping the gas line open. When the flame goes out, a thermal device and retaining spring force the holding magnet assembly away from the ring, shutting off the gas supply.

We shall be glad to help you also with your magnet application problems. Backed by years of research and magnet design experience, General Electric engineers are always at your service.

The precise quality control methods used throughout G-E magnet production plus accurate testing and rigid inspection, assure you of receiving magnets of the highest uniform quality for your application.

Moreover, greater flexibility of magnet design is possible with the many G-E permanent magnet materials now available. These include cast and sintered ALNICO, the ductile alloys CUNICO, CUNIFE and SILMANAL and lightweight non-metallic VECTOLITE. *Metallurgy Division, Chemical Department, General Electric Company, Pittsfield, Mass.*

Send for our new bulletin, CDM-1, "G-E Permanent Magnets," specifically designed to help you with your permanent magnet problems. This bulletin contains information about the characteristics and properties of G-E permanent magnet materials, their application and design.

METALLURGY DIVISION, Sec. L A-9
CHEMICAL DEPARTMENT
GENERAL ELECTRIC COMPANY
PITTSFIELD, MASS.

Please send me your new bulletin, CDM-1, "G-E Permanent Magnets."

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PERMANENT MAGNETS

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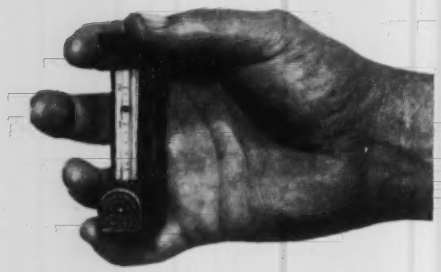
CDM7-JA6

FLOW RATE METER ELIMINATES "BUBBLE COUNTING"



This compact flow meter is the answer to purge line (Bubbler) control installation.

. . . true purge rate indication
. . . easily and neatly panel mounted singly or in multiple, requires a minimum of space.
. . . furnished with or without needle control valve.

$9.00 per unit, without control valve (lower price when purchased in quantity).

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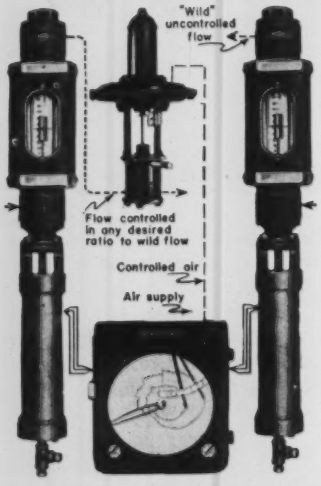

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Manufacturers' New Literature

In this department we report new literature pertaining to Instrumentation, received from manufacturers. We urge readers to request ONLY those bulletins which will be of value to them. Use the Postage-free Order Card on page 869.

O-419 **Metrology.** 5-sheet 8½" × 11" descriptive articles on the company's new line of imported (French) "Sagem" precision measuring and gaging instruments. Pictures and describes the Universal Comparator sight and the Vertical Metrological Comparator. E. Leitz, Inc., 304 Hudson St., New York 13, N. Y.

O-420 **Hydrauliscope.** 4-page 8½" × 11" Bulletin No. 109 illustrates and describes the "Aeroquip Hydrauliscope," a compact, portable instrument with controls and adjustment facilities simple but sufficient enough for anyone to accurately analyze hydraulic pressure phenomena. Aeroquip Corporation, Jackson, Mich.

O-421 **Pyrometers and Temperature Controllers.** Nine 8½" × 11" sheets containing illustrations and descriptions of "Xactline" temperature control and measurement devices for temperature reading of heat-treating applications and molten metals, as well as the new Capacitrol, a combination of the Xactline Control Unit and Wheelco Capacitrol. Claud S. Gordon Co., Cleveland, Ohio.

O-422 **Moisture Tester.** 4-page 3½" × 6¼" Bulletin AL-24 pictures and describes "Speedy" Moisture Tester for determining moisture content of sands, ganister, clays, oxides, etc., within 40 seconds. Directions for operation are included. The Alpha-Lux Co., Inc., 155 John St., New York 7, N. Y.

O-423 **Metricator.** 12-page 8½" × 11" bulletin presents illustrations and descriptions of the new "Federal-Metricator" Dimensional Air Gage. Diagrams accompany the explanation of its special features—high amplification, foolproof gaging operation, longer gaging-head life, etc. Federal Products Corp., 1144 Eddy St., Providence, R. I.

O-424 **Insulation Tester.** 2-page 7¾" × 10½" Bulletin No. 21-46 diagrams and explains the "plug-in" type "Megger" Insulation Tester which is especially useful where a large number of tests are to be made, and also where individual tests continue for many minutes. James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.

O-425 **Magnetic Relays.** 8-page 8½" × 11" Bulletin 570 outlines the applications of electrical ratings and magnet coils, and the construction of general-purpose magnetic relays. Also charts cataloging a-c. and d-c. relays. R-B-M Division, Essex Wire Corp., Logansport, Ind.

O-426 **Noise Suppressor.** 8-page 6" × 9" bulletin describes Type 910A Dynamic Noise Suppressor for use with phonograph records. Illustrations show operation and construction details. Technology Instrument Corp., 1058 Main St., Waltham 54, Mass.

O-427 **Electronic Analyzer.** 2-page 8½" × 11" bulletin pictures and describes new Electronic Analyzer Model 769 and its applications in the high-frequency and VHF fields as well as general test... Includes complete technical data. Weston Electrical Instrument Corp., Newark 5, N. J.

O-428 **"Modern Precision."** 8-page 10... × 15½" Vol. 7, No. 1 of this house organ reports the applications of the Speedomax High-Speed Indicator, Microphotometer, Micromax Pyrometers and Recorders, and K-2 Potentiometer. Illustrations and descriptions cover fields of metallurgy, ceramics, power, process industries, research, teaching and testing. Leeds & Northrup Co., 4902 Stenton Ave., Philadelphia 44, Pa.

O-429 **Torque Tools,** 4-page 8½" × ... loose-leaf fillers cover the "Trutorq" line of calibrated screw drivers, foot-pound and spark-plug wrenches. Pictures the... and describes use, calibration, strength, etc. Airdraulics Engineering, New Canaan, Conn.

O-430 **High-vacuum Thermocouple Gaging.** 4-page 8½" × 11" bulletin illustrates and explains the NRC Type ... gage control, Type 501 high-vacuum gage, Type 705 "Protectovac" and Type 702 gage adapter unit, with physical and operational specification lists. National Research Corp., 70 Memorial Dr., Cambridge 42, Mass.

O-431 **Controls and Resistors.** 4-page 8½" × 11" Bulletin No. 142 pictures and describes Series 42 Multiple-unit Wire-wound Controls which offer simultaneous control of a plurality of circuits or functions. Clarostat Mfg. Co., Inc., 285-7 6th St., Brooklyn, N. Y.

O-432 **Transformers, Patch Cords and Plugs.** 16-page 8½" × 11" Catalog ... 46A lists the maker's line of transformers, including AM and FM, power, and industrial transformers. Also illustrates and describes jacks and jack panels, plugs and patch cords of various types. Audio Development Co., 2833 13th Ave. S., Minneapolis 7, Minn.

O-433 **"Engineering Notes."** 8-page 8... × 11" Vol. 2, No. 3 of this house organ contains three articles covering the Weston Photographic Analyzer, Vacuum Thermoelements, and Organization of an Electrical Instrument Standardizing Laboratory. Diagrams, charts and pictures also included. Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.

O-434 **Boiler-feed Regulator.** 12-page 8½" × 11" Bulletin No. 429B illustrates and describes the "Copes Flowmatic" Regulator for automatic boiler feed in accord with steam flow, as well as direct-operated regulators. Northern Equipment Co., Erie, Pa.

O-435 **Ratio Test Set.** 4-page 8½" × 11" Bulletin No. 55 pictures and explains the new portable instrument, Muirhead Transformer Turn Ratio Test Set, for simple, direct testing. James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.

O-436 **Combustion Control.** 2-page 8½" × 11" Installation Bulletin CG 4751 diagrams and outlines the "Fireye" Combustion Control System FF-6 which provides operating protection for industrial and commercial gas burners. Combustion Control Corp., 77 Broadway, Cambridge 42, Mass.

O-437 **Electronic Instruments.** 6-page 8½" × 11" catalog describes in ample technical details: (1) "Type 301 Electronic Microammeter" which detects .0002 microamp. and is ranged 0.01, 0.1, 1, 10 and 100 microamps; (2) "Type 201" portable high-voltage power supply with output continuously variable from 0 to 30 kv.; (3) "Series 101" low-burden d-c. kilovoltmeters, each a single-range instrument: 15, 30 and 50 kv., (4) "Series 111" low-burden d-c. kilovoltmeters with ranges of 100 and 150 kv. respectively. Beta Electronics Co., 1762 Third Ave., New York 29, N. Y.

O-438 **"Characteristics of Pneumatic Diaphragm Motors."** 8-page 8½" × 11" article by R. B. Werey reviews fundamentals and presents a considerable amount of useful quantitative data with five diagrams, three sets of curves and four photographs, as well as tables. Conoflow Corp., 2100 Arch St., Philadelphia 3, Pa.

O-439 **Signal Generator.** 2-page 8½" × 11" Bulletin 299-A announces new Model Standard R-F Signal Generator. Complete specifications given. Clough-Brengle Co., 1914 Broadway, Chicago, Ill.

O-440 **Voltage Control.** 12-page 8½" × 11" Bulletin No. 547 illustrates and describes "Powerstat" line of variable transformers. Recent design advancements and new developments are included. Superior Electric Co., Bristol, Conn.

O-441 **Automatic Controls.** 64-page 8½" × 11" Catalog No. 600A completely covers maker's line of automatic controls for heating, air conditioning, refrigeration and other industrial applications. Descriptions are accompanied by illustrations, diagrams and specifications. The Mercoid Corp., 4201 Belmont Ave., Chicago, Ill.

O-442 **Electric Timers.** 4-page 8½" × 11" brochure pictures and describes maker's line of interval and automatic reset timers, time delay relays, cycle and impulse timers, duplex cycle timers, running time meters and time relays. R. W. Cramer Co., Centerbrook, Conn.

O-443 **Valves.** 6-page 9"×12" folder describes, with illustrations and diagrams, maker's line of solenoid valves for water, air, gas, steam, oil and all media not harmful to bronze. Atkomatic Valve Co., 1255 Roosevelt Ave., Indianapolis 7, Ind.

O-444 **Combustible Gas Alarm System.** 4-page bulletin pictures and describes maker's system for detection and measurement of gas or vapor air concentrations in terms of their explosibility. Davis Emergency Equipment Co., 45 Halleck St., Newark 4, N. J.

O-445 **"Streamlined Planning."** 6-page 8½"×11" folder outlines how modern planning has been applied to "Stancor's" new plant for stepping up production, lowering cost and expediting handling of larger stocks. Standard Transformer Corp., Elston, Kedzie and Addison, Chicago 18, Ill.

O-446 **Time Delay Relay.** 2-page 8½" × 11" Bulletin No. 900B illustrates and describes "Type TC" Time Delay Relay. Included are its functions, applications and

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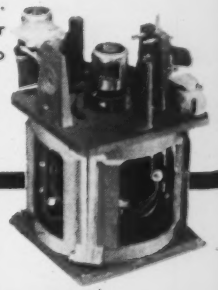

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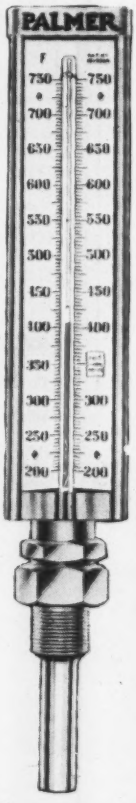

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indicators are included. W. & L. E. Gu... ley, Troy, N. Y.

O-448 **Percentage Timer.** 2-p... 8½" × 11" Bulletin No. 2500C illust... lists the functions, applications, ... construction and price of "Type E" Per... centage Timer. R. W. Cramer Co., Center... brook, Conn.

O-449 **Scales.** 14-page 8½" × 11" bu... letin pictures and describes ma... of dynamometer scales for measuring ... tension and force, especially ad... laboratory and shop testing devices. John Chatillon & Sons, 85-93 Cliff Stree... N. Y. 7, N. Y.

O-450 **Combustible Gas Detection.** ... page 8½" × 11" bulletin pictures and de... scribes "Model 5 Vapotester" for dete... tion of combustible gases or vapors. Fea... tured is the method of locating leaks ... underground gas mains and service lines. Davis Emergency Equipment Co., 45 H... leck St., Newark 4, N. J.

O-451 **Running Time Meter.** 2-page 8½ × 11" Bulletin No. 3500B pictures and de... scribes "Type E" models for use on a... circuits to automatically and cumulative... ly register the total operating time, ... idle time of any circuit, machine or sy... tem. R. W. Cramer Co., Centerbro... Conn.

O-452 **Pulse Timer.** 2-page 8½" × 1... Bulletin No. 1600 pictures and describ... "Type V" for repeating continuously ele... trical impulses of a definite set durati... at the end of successive identical ti... intervals. R. W. Cramer Co., Centerbro... Conn.

O-453 **High-vacuum Apparatus.** 48-pa... Bulletin 10 points out some of the fa... tors to be considered in choosing and o... erating vacuum equipment; lists make... high-vacuum pumps and pump acce... sories. Central Scientific Co., 1700 Irvi... Park Road, Chicago 13, Ill.

O-454 **"The Ohmite News."** 2-page iss... of this house organ features new "Ty... AB2" Watt Potentiometer. Ohmite Ma... facturing Co., 4835-41 Flournoy St., Ch... cago 44, Ill.

O-455 **"The Capacitor."** 16-page Vol. ... No. 6 issue of this house organ featur... "Electronic Photoflash Units." Corne... Dubilier Electric Corp., Hamilton Blvd., So. Plainfield, N. J.

O-456 **Twin Seal Test Unit.** 6-page 8½ × 11" folder pictures and describes a hy... drostatic test unit equipped with tw... seal check valves for portable testin... bench comparator testing, and ben... dead-weight testing of pressure gag... and pressure instruments. Mansfield ... Green, Powers Ave. & East Ninth St., Cleveland, Ohio.

O-457 **"The General Radio Experimen... ter."** 8-page Vol. 22, No. 1 issue of th... house organ features "Increased Accur... cy for the Precision Condenser." Gener... Radio Co., 275 Massachusetts Ave., Cam... bridge 39, Mass.

O-458 **Continuous-flow Steam Trap.** ... page 8½" × 11" Catalog No. 903 B pa... tures and describes "Drainator" whi... utilizes a new principle for the remov... of condensate and air. Coe Manufacturi... Co., Painesville, Ohio.

O-459 **Oil Country Gages.** 16-page 8½ × 11" booklet relates the story of the s... lection by the A P I of marker's "Gra... Master" Gages for the establishment ... the A P I's standardization program. I... cluded is a description of the gag... Pratt & Whitney, West Hartford 1, Co...

O-460 **Relays.** 4-page 8½" × 11" br... chure pictures and describes maker's r... lays for electrical equipment and co... trols. American Relay and Controls, In... 2555 Diversey Ave., Chicago 47, Ill.

O-461 **Glass Specialties.** 2-page 8½" × 11" Catalog Section 95-D lists the available sizes in "Precision Bore" round capillary tubing (heavy wall), round tubing (standard wall), and square tubing. Fischer & Porter Co., Hatboro, Pa.

O-462 **"Engineering Data and Reference Tables."** 12-page 8½" × 11" Bulletin No. 467, a compendium of handy information for calculations on piping, pumps, heaters, traps, reducing valves, temperature regulators, pump governors, pressure controllers and other such equipment. Leslie Co., Lyndhurst, N. J.

O-463 **"Recordings"** 4-page 8½ × 11" Vol. 1, No. 2 issue of this house organ features "Cancer Research Aided by New Mass Spectrometer" and other short articles of interest. Consolidated Engineering Corp., 620 N. Lake Ave., Pasadena 4, Calif.

O-464 **Electronic Resistance Thermometer.** 12-page 8½" × 11" Bulletin 230-B pictures and describes the "Pyroton" which records as may as four temperatures by continuous record and is suitable for marine, mobile or other classes of severe service. Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.

O-465 **Selenium Rectifiers.** 8-page 8½" × 11" bulletin lists the characteristics, applications and design factors of "Seletron" selenium rectifiers. Radio Receptor Co., 251 W. 19th St., New York 11, N. Y.

O-466 **"Analysis of Measurement."** 28-page 8½" × 11" Booklet GET-1344 gives a comprehensive functional analysis and classification of measurement systems and outline of other historical developments. General Electric Co., Schenectady, N. Y.

O-467 **Test Set for A-c. Power.** 4-page 8½" × 11" Bulletin GEA-4784 pictures and describes the "A-c. Load Visualizer Type AF-1" which embodies an advanced principle of instrument design to meet the need for a small light-weight analyzer with all readings on a single dial. General Electric Co., Schenectady, N. Y.

O-468 **Recording Gages and Thermometers.** 16-page 8½" × 11" Bulletin T835 pictures and describes maker's line of gages and thermometers with the design requirements of the "Series 500" recorder. The Bristol Co., Waterbury, Conn.

O-469 **Resonant Relays.** 2-page 8½" × 11" Catalog No. 116A pictures and describes relays for remote control by radio or carrier current though frequency discrimination. Stevens-Arnold Co., 22 Elkins St., So. Boston 27, Mass.

O-470 **Quality Control.** 8-page 8½" × 11" booklet covers two subjects. (1) "Charts help diagnose quality progress" and (2) "How to analyze production rejects." North American Phillips Co., 100 E. 42nd St., New York 17, N. Y.

O-471 **Timing Motor.** 4-page 8½" × 11" Bulletin No. 10 pictures and describes maker's "Type SX" self-starting synchronous timing motor. R. W. Cramer Co., Centerbrook, Conn.

O-472 **Potentiometers.** 24-page 8½" × 11" Catalog 15-11 pictures and describes maker's electronic potentiometers employing "Continuous Balance" principle. Brown Instrument Co., Philadelphia 44, Pa.

O-473 **"Electronic-Pneumatic-Mechanical Instrumentation,"** 32-page 9" × 11½" Vol. 2, No. 6 issue of this house organ carries a number of articles on industrial process control and covers humidity, temperature, moisture content, gas analysis, heat treating, etc. The Brown Instrument Co., Philadelphia 44, Pa.

O-474 **Electronic Instruments.** 8-page 8½" × 11" Bulletin 397 pictures and de-

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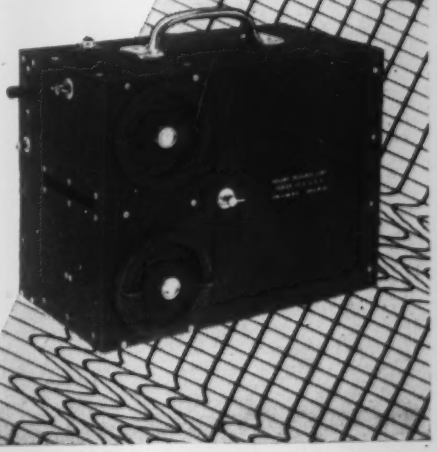

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